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FORECASTING CUTOVER RESPONSE IN NEW BRUNSWICK A GUIDE FOR SILVICULTURAL DECISION MAKING

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FORECASTING CUTOVER RESPONSE IN NEW BRUNSWICK A GUIDE FOR SILVICULTURAL DECISION MAKING

By

Betty Godin

Timber Management Branch

Department of Forests, Mines and Energy

Province of New Brunswick

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ABSTRACT

A "Preliminary Guide to Forecasting Cutover Response" has been developed for the mature-overmature fir-spruce and spruce-fir cover types throughout central and northern New Brunswick. This guide is intended to aid silvicultural decision making by forecasting the regeneration patterns that result after harvesting.

A set of dichotomous keys form the structure of the field guide. Keys have been developed to forecast:

1) the precut fir and spruce advance growth associated with various overstory structures and compositions,
2) the survival of fir and spruce advance growth after summer harvesting with skidders and forwarders,
3) the probability of obtaining $\geqslant$40% and $\geqslant$60% softwood (fir + spruce) stocking after summer harvesting,
4) the probability of obtaining $\geqslant$40% and $\geqslant$60% spruce stocking after summer harvesting.

The guide has been designated as preliminary as a limited range of conditions have been sampled and no field testing has to date been completed.

Although insufficient data were available for the development of keys, the report also discusses the postcut establishment of fir and spruce seedlings, the effect of winter harvesting and the postcut establishment of hardwoods.

TABLE OF CONTENTS

	Page
ABSTRACT	ii
LIST OF TABLES	v
LIST OF FIGURES	v
ACKNOWLEDGEMENTS	vii
INTRODUCTION	1
SAMPLING PROCEDURES	6
Methodology	6
Plot Establishment	7
Uncut Plots	8
Advance Growth Tally	8
Overstory Tally	8
Cutover Plots	9
Regeneration Tally	9
Stump and Residual Tally	9
Collection of Fir and Spruce Seedlings For Ageing	10
RESULTS AND DISCUSSION	11
Precut Conditions	11
Predicting the Fir and Spruce Advance Growth	11
Division of Stands	12
Group 1 Stands	15
Group 2 Stands	21
Group 3 Stands	23
Postcut Conditions	24
Origins of the Fir and Spruce Regeneration	24
Predicting the Postcut Fir and Spruce Regeneration	29
Plot Pairs	29
Relationships to the Precut Stand	32
Relationships Between the Postcut Density and Stocking Levels of Fir and Spruce	40
Postcut Hardwoods and Shrubs	46

Page

RECOMMENDATIONS FOR FURTHER STUDY 50

LITERATURE CITED 57

APPENDICES

I. PRELIMINARY FIELD GUIDE TO FORECASTING CUTOVER RESPONSE FOR FIR-SPRUCE AND SPRUCE-FIR STANDS 58

II. LIST OF TREE AND SHRUB SPECIES 70

LIST OF TABLES

		Page
Table 1.	Origins of the fir and spruce regeneration in the cutovers	26
Table 2.	Percent of the cutovers having ⩾60% and ⩾40% stocking of fir and spruce after skidder and forwarder operation. Percentages are calculated from the surviving advance growth alone (1) and with the inclusion of seedlings that established after harvesting (2)	44

LIST OF FIGURES

Figure 1.	Study area locations	4
Figure 2.	Diameter distributions for the 3 groups of stands. Means are ± 1 S.E.	13
Figure 3.	Relationships between the number of fir advance growth and the percentage of spruce in the overstory for the 3 groups of stands	16
Figure 4.	Relationships between the number of spruce advance growth and the percentage of spruce in the overstory for the 3 groups of stands	17
Figure 5.	Relationship between the percent stocking and the number of fir advance growth	18
Figure 6.	Relationship between the percent stocking and the number of spruce advance growth	19
Figure 7.	Relationship between the percent stocking and the number of fir and spruce advance growth combined	20

		Page
Figure 8.	Survival of fir advance growth after skidder and forwarder operations as determined from the plot pairs	31
Figure 9.	Survival of spruce advance growth after skidder and forwarder operations as determined from the plot pairs	31
Figure 10.	Survival of fir advance growth after skidder and forwarder operations for Group 1 stands	33
Figure 11.	Survival of spruce advance growth after skidder and forwarder operations for Group 1 stands	34
Figure 12.	Survival of fir advance growth after skidder and forwarder operations for Group 2 stands	35
Figure 13.	Survival of spruce advance growth after skidder and forwarder operations for Group 2 stands	36
Figure 14.	Relationship between the percent stocking and the number of fir seedlings in the cutovers	41
Figure 15.	Relationship between the percent stocking and the number of spruce seedlings in the cutovers	42
Figure 16.	Relationship between the percent stocking and the number of combined fir and spruce seedlings in the cutovers	43
Figure 17.	Accuracy in matching the merchantable overstory fir and spruce in the plot pairs	52
Figure 18.	Accuracy in matching the merchantable overstory spruce in the plot pairs	53
Figure 19.	Accuracy in matching the nonmerchantable overstory fir and spruce in the plot pairs	54

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INTRODUCTION

In the province of New Brunswick a commitment has been made towards an intensive forest management program with the aim of increasing the productivity of the forest resource and hence maintaining a wood supply for the future. With the implementation of the Crown Lands and Forest Act in 1982, guidelines were set for the management of the forest resource in order to accomplish this objective.

A major aspect of the management program involves the immediate regeneration of the forest after harvesting. Although it is established that some level of silviculture is required to accomplish this task, a lack of information is available to efficiently direct such treatments. With limited expenditures for silviculture in an operating plan, it is important to employ such treatments where they are most necessary and will produce the highest return. In this way, both natural and artificial regeneration could be utilized to the fullest potential to maximize forest productivity.

To accomplish this task, an ability is required to forecast cutover response patterns that would result from harvesting different forest cover/site types with different harvesting systems. This would enable better forecasting of the silvicultural requirements such as scarification and planting. As well, the possibility would exist to more efficiently utilize silvicultural efforts by directing cut-

over response patterns. This may be accomplished by integrating the cut block layout and the selection of the harvesting system with the forest cover/site types to produce the most desirable and the most homogeneous cutover response patterns.

Although this study is aimed at silvicultural decision making and therefore covers only the initial postharvest response (approx. 5 years after harvesting), the ability to forecast this period also influences the accuracy of predicting the future yield from the cutovers.

The following report discusses aspects of the forest cover/site and the harvesting system that have been found to most strongly influence the cutover response patterns. Summaries of the data analyses are also presented in the form of "dichotomous keys" which comprise a "Preliminary Field Guide To Forecasting Cutover Response For Fir-Spruce and Spruce-Fir Stands" (Appendix I). The keys at this stage are preliminary because of the limited range of conditions that have been sampled and the absence to date of adequate field testing.

The work to date has been concentrated in the mature-overmature fir-spruce (scientific names are given in Appendix II) and spruce-fir cover types throughout northern and central New Brunswick. Stands with >10% cedar, pine, tamarack or hemlock were excluded from the study. Although spruce budworm (Choristoneura fumiferana (Clem.)) defoliation pressures varied throughout the stands, no areas were

sampled which would be considered salvage operations or in which the fir component had been destroyed such that the classification of the overstory would change from a fir-spruce combination to a more pure spruce cover type. Modification of the present forecasting system would be required to incorporate such conditions of spruce budworm devastation.

Although the intention for the study was to utilize data that had already been collected largely by the Department of Forests, Mines and Energy (DFME), they were found to be incomplete for the development of a predictive tool and were therefore of use mainly in the formation of hypotheses. Problems associated with the utilization of the data were related primarily to 1) the sampling intensity within a forest cover strata, 2) incomplete counts of both the precut advance growth and the postcut regeneration and 3) an inability to obtain the precut stand composition and structure for the cutovers. The data presented in the report were collected specifically for the study under funding from a Federal "Environment 2000" grant and with assistance from industry. This consists of 80 cutovers and 40 uncut stands. In addition, 8 cutovers and 19 uncut stands are included from the authors MScF thesis project (Godin, 1982).

Sampling was concentrated in 3 different geographic areas of the province (Fig. 1). About 1/3 of the plots were in the northwest (Area 1) on acidic to neutral fine-

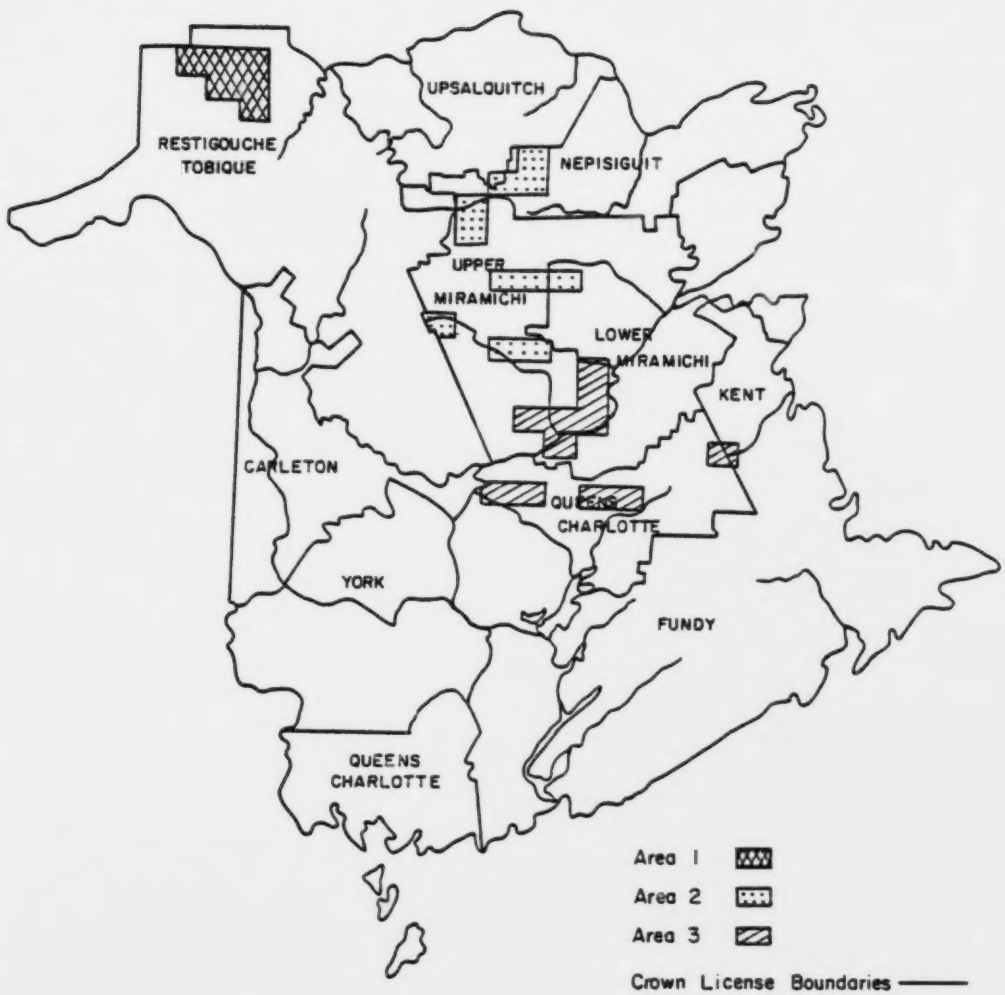

Figure 1. Study area locations.

textured sediments (siltstone, shale, sandstone), 1/3 from central N.B. (Area 2) on granites, volcanics, greywackes and phyllites and 1/3 in southeastern N.B. (Area 3) on acidic coarse-textured sediments (sandstone, siltstone, shale). All plots were on Crown land.

SAMPLING PROCEDURES

METHODOLOGY

With a limited time frame and funding for field work, it was not feasible to study cutover response through the preferred method of obtaining a preharvest sampling followed by a postharvest sampling of the same stand. As an alternative, two methods were employed to relate the precut and postcut conditions.

A system of "plot pairing" was used where neighbouring uncut and cutover stands could be matched by forest cover and bedrock types. The stands were paired on the provincial black and white 1:20 000 photography on which the precut forest cover for the cutover plots could be interpreted and paired with the uncut stands. The pairs were then transferred to photos showing the cutover condition (either 1:12 500 colour or black and white cut photography). The assumption is made in this pairing that the associated advance growth for the uncut stand also represents that which existed for the cutover stand in its precut condition. This system of plot pairing has been employed in previous work (Godin, 1982) and is considered a satisfactory method of obtaining trends in cutover response. Stump tallies were also obtained in the cutovers as a check of the pairing.

Where uncut pairs were not available, an alternate

method of using stump and residual tree tallies to reconstruct the precut stand was employed. The advance growth that would have been associated with the precut stand was then inferred from correlations developed between the overstory and advance growth for similar stands.

PLOT ESTABLISHMENT

Plots were established in fir-spruce and spruce-fir stands having at least 5 ha of homogeneous forest cover. In each of the uncut and cutover stands, 20 points were established at 25 m intervals along lines spaced within an area of approximately 5 ha. All lines were spaced 50 m apart and were 50 m from any forest edge, landing, or road.

In the cutovers, all lines were established perpendicular to the direction of harvesting and to the slope. All cutovers were approximately 5 years of age (accepted from 3-8 years) and had no silvicultural treatment.

In the uncut stands, the lines were also oriented perpendicular to the slope whenever possible. This was not always the case however, because of a limited availability of area for uncut pairs.

Uncut Plots

Advance Growth Tally

At each of the 20 points along the lines, a 5 m^2 circular plot was first established to tally the advance growth. All tree seedlings (Appendix II) were tallied over the entire plot. A selected list of shrubs (Appendix II) that are considered to have a possible effect on fir and spruce regeneration were assessed only in the right hand quarter of the plot facing the line of travel. All species were tallied in the following height classes:

Height Class (cm)
1. 0-15
2. 15.1 - 45
3. 45.1 - 75
4. 75.1 - 130 (breast height)

Overstory Tally

A prism tally was also taken at each point to determine the overstory composition. All trees (Appendix II) were tallied by species in 2 cm diameter classes. Nonmerchantable (2-8 cm dbh classes) stems were included as well as the merchantable trees ($\geqslant$10 cm class).

Cutover Plots

Regeneration Tally

In the cutovers, each of the 20 points formed a centre for a 5 m^2 circular plot in which the regeneration was tallied. As with the uncut stands, the tree seedlings were counted in the entire plot and the shrubs in the upper right hand quarter. The regeneration was not tallied by height classes but the height of the tallest individual of each species was recorded. This assessment was also made over the entire plot for the tree species and in the upper right hand quarter for the shrubs.

Stump and Residual Tally

The stumps and residual stems were tallied in six 5 m radius plots. Two centre points were located at even spacings in the cutover area and 3 plots radiated at 120° angles from each centre. The distances of the plots from the centre points were randomly chosen.

In each 5 m radius plot, all stumps and residuals were measured at 10 cm above the ground and tallied in 2 cm diameter classes. The conversions from stump diameter to breast height diameter were taken from Honer *et al.*, 1983. To maintain consistency with the tallies made for the uncut overstory, only residuals that were greater than 130 cm at the time of harvesting were included.

COLLECTION OF FIR AND SPRUCE SEEDLINGS FOR AGEING

From the centre of each of the 5 m^2 regeneration plots, the closest fir and the closest spruce seedling was collected. Spruce layers were infrequent in the study areas, however, they may have been included if they showed an upright seedling form. As the plots were spaced at 25 m intervals, only an area with a 12.5 m radius was searched for seedlings.

The seedlings were cut just below the root collar or for those less than 20 cm in height, the entire seedling was collected. Seedling ages were obtained in the laboratory by using a compound microscope (10x).

RESULTS AND DISCUSSION

PRECUT CONDITIONS

Predicting the Fir and Spruce Advance Growth

There are many factors relating to the composition and structure of the stand and the site that influence the density, height distribution and stocking of the fir and spruce advance growth. Although several studies of harvesting in fir-spruce cover types have, in some manner, related the precut advance growth to the postcut conditions (e.g. Westveld, 1931; Vincent, 1956; Hatcher, 1960; Webber et al., 1969; Weetman et al., 1973; and Frisque et al., 1978) no quantitative system for forecasting cutover response from a precut stand description has been developed. In an attempt to develop such a system, the first step in this study was to determine the controlling links between the overstory and the advance growth patterns.

After considerable examination of the various stand conditions, it was concluded that 2 factors, the density of the fir and spruce and the proportion of fir to spruce in the overstory contributed most strongly to the patterns of fir and spruce advance growth. As the majority of the spruce in the study area were red-black hybrids or black spruce, reference will be made throughout to spruce in general and individual species will not be separated.

Division of Stands

After the major controlling factors were identified, the stands were divided into 3 groups on the basis of their similarity of overstory - advance growth patterns. The density of the overstory fir and spruce was used as the primary factor in dividing the stands. Groups 2 and 3 were further divided by the proportion of nonmerchantable (2-8 cm classes) fir and spruce. Within each group, the advance growth is related to the secondary factor, the proportion of spruce to fir in the overstory. This will be expressed as the percentage of spruce and calculated as follows:

$$\frac{\text{number of spruce} \geq 10 \text{ cm dbh}}{\text{number of fir + spruce} \geq 10 \text{ cm dbh}} \times 100$$

Group 1 includes all stands with < 1200 stems/ha of overstory fir and spruce. Groups 2 and 3 both have densities of ≥ 1200 fir and spruce/ha, however, the nonmerchantable stems for Group 2 are $< 50\%$ of the total fir and spruce densities and $\geq 50\%$ for Group 3.

As well as variable densities, the 3 groups of stands also show distinct diameter distributions (Fig. 2). Group 1 stands show a relatively low number and even distribution of stems up to 24 cm dbh. These stands also have the highest proportions of the larger diameter stems (26 cm+). Group 2 stands are dominated by stems in the 10-16 cm diam-

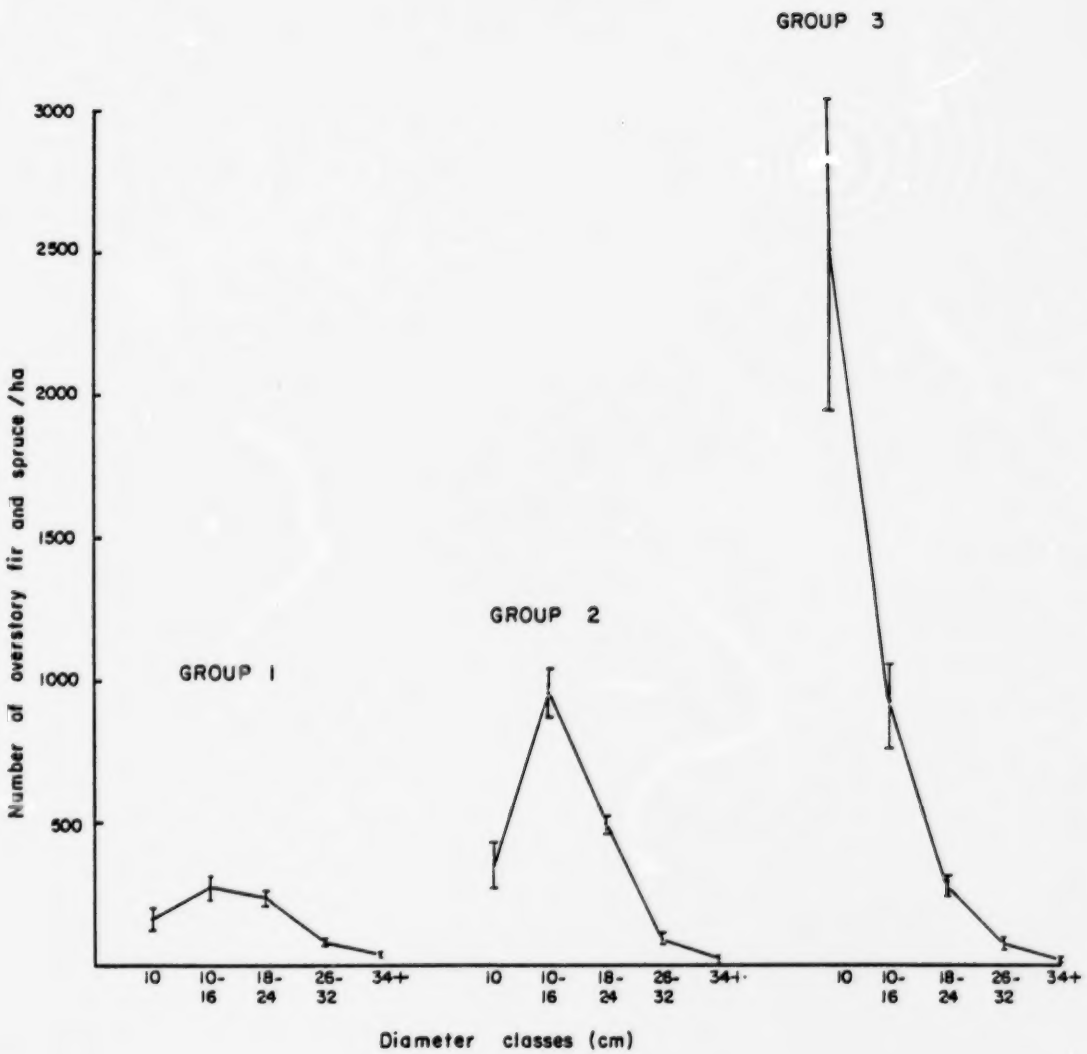

Figure 2. Diameter distributions for the 3 groups of stands. Means are ±1 S.E.

eter range and have an average stand diameter less than that of Group 1 stands. Group 3 stands have by far the lowest average stand diameters which are a result of the dominance of the nonmerchantable stems (2-8 cm dbh).

Overall, the percentages of hardwoods were found to vary within the groups from 1% to almost 40% of the total overstory density. Group 1 stands had the highest hardwood densities which in conjunction with low softwood densities approached a mixedwood condition. Stands in Groups 2 and 3 generally did not have hardwood densities above 20% of the total overstory densities.

Various bedrock and soil types were also covered within each group. Site appears to influence the advance growth in a more indirect manner through the overstory. The species composition and structure of a stand are generally related to the site however, this may be altered by a complex of interactions such as spruce budworm epidemics, birch dieback, fire and selective cutting. Although no attempt will be made to discuss these interactions, there were some obvious concentrations of stand types associated with various sites in the study areas.

In the northwest on the well-drained, fine-textured, acidic to neutral sediments (Area 1, Fig. 1), the highest concentration of Group 1 stands occurred. On the granites, volcanics, greywackes and phyllites in the central part of the province (Area 2), Group 2 stands are most common. The stands in this area were also on well-drained soils. Mov-

ing southeast onto the more coarse-textured acidic sediments (Area 3), the soils are more commonly imperfectly to poorly drained. As black spruce predominates on these soils and as it is often dense and of a small diameter range, Group 3 stands are common. On higher knolls however, where drainage is improved, fir-spruce mixtures generally of low density (Group 1 stands) were more typical.

Figures 3a, b and c (curves are hand-fitted) show the patterns of fir advance growth and Figures 4a, b and c (curves are hand-fitted) the patterns of spruce advance growth for the 3 groups of stands. Each sample point represents a stand average. Advance growth densities have been presented because they show the greatest sensitivity to overstory changes. However, density and stocking show correlations for both fir and spruce advance growth. Stocking values for the advance growth densities are presented in Figures 5 to 7 (curves are hand-fitted). Each sample point represents a stand average.

Group 1 Stands

The densities of both fir and spruce advance growth show an increasing trend with an increasing percentage of spruce in the overstory. There are, however, considerable changes in the densities from a pure fir to a pure spruce condition of the stand. Fir advance growth densities increase from approximately 10,000 to 50,000 seedling/ha (Fig. 3a) while spruce has a somewhat sharper increase from

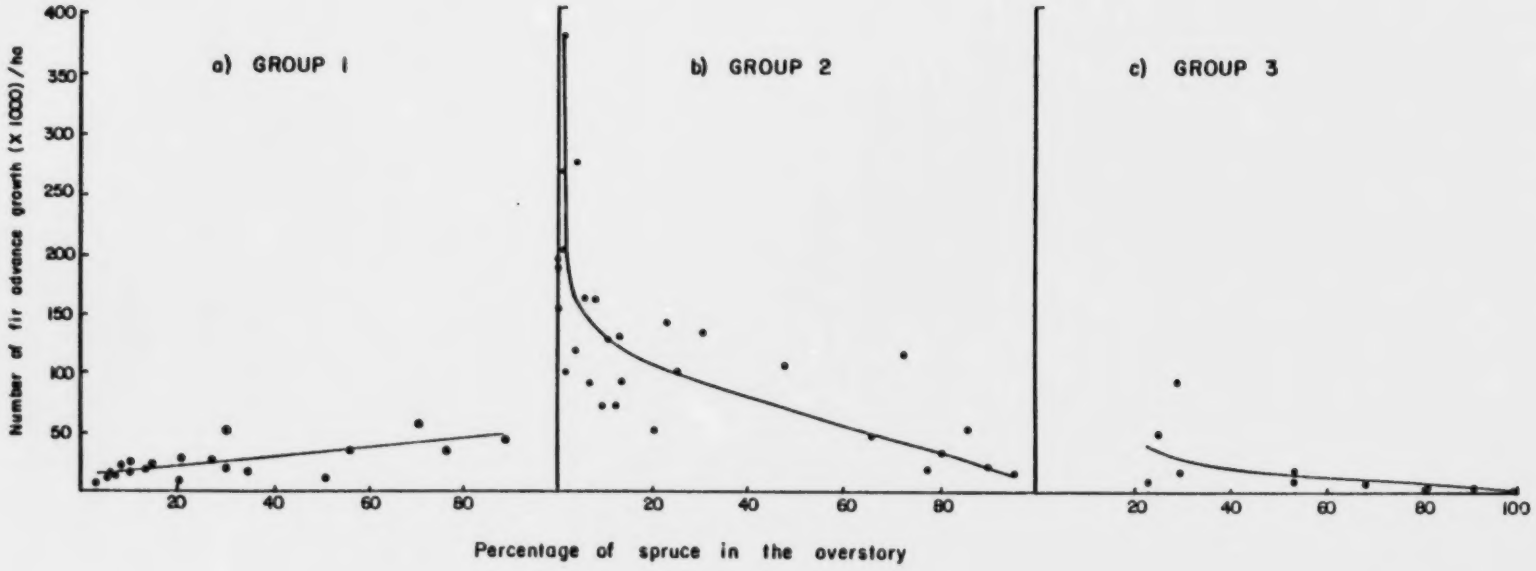

Figure 3. Relationships between the number of fir advance growth and the percentage of spruce in the overstory for the 3 groups of stands.

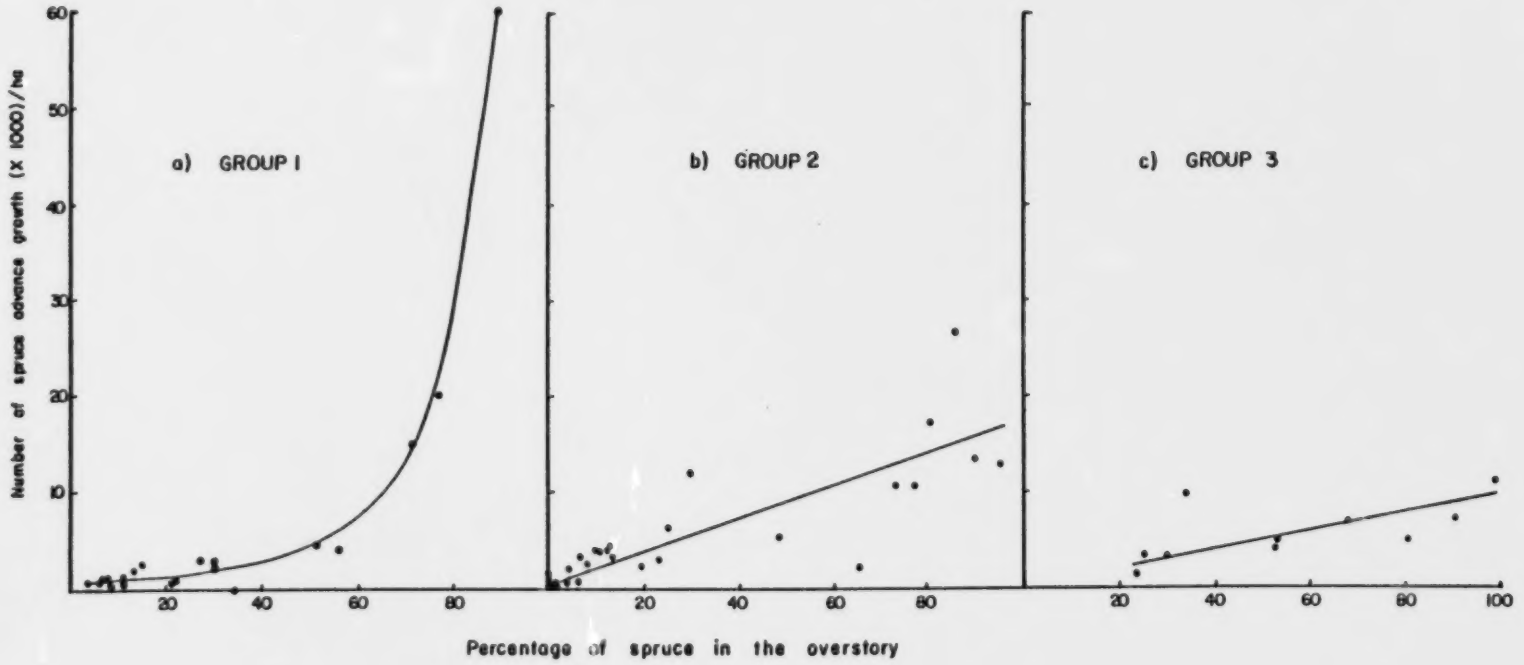

Figure 4. Relationships between the number of spruce advance growth and the percentage of spruce in the overstory for the 3 groups of stands.

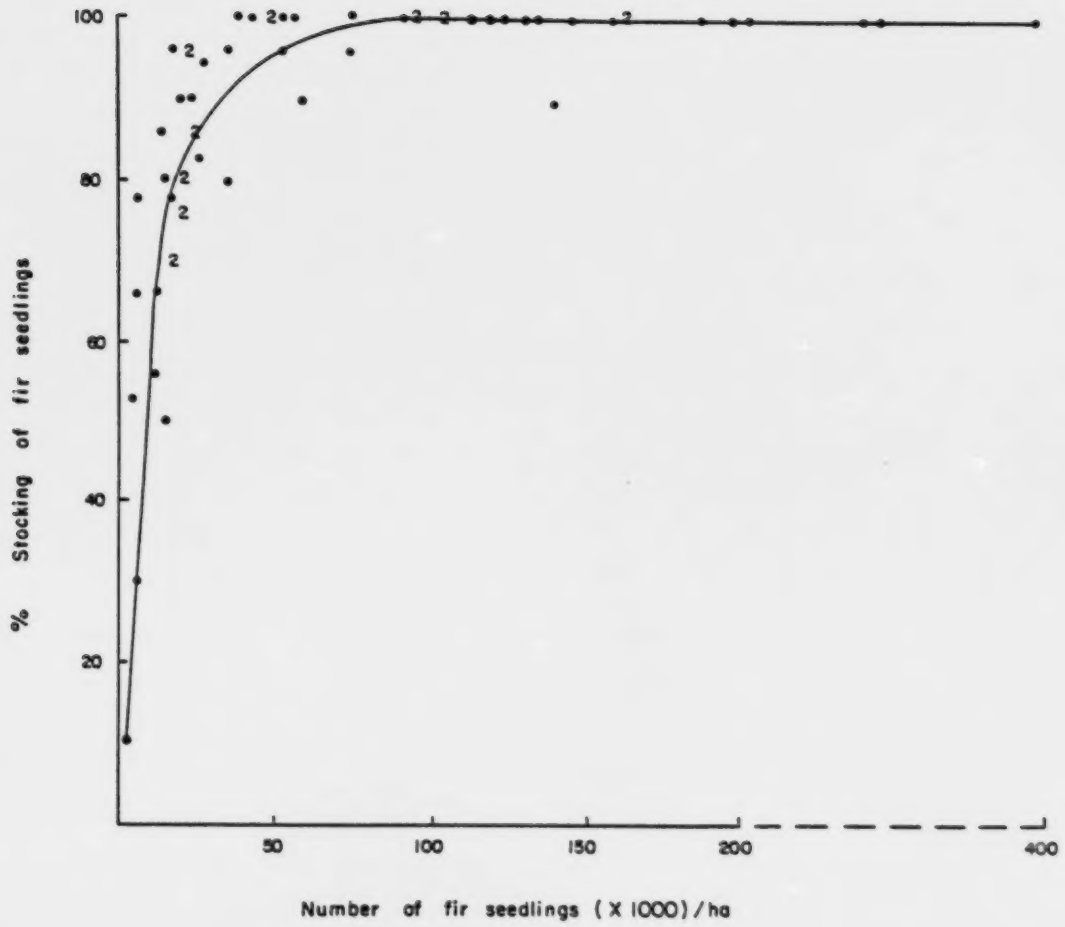

Figure 5. Relationship between the percent stocking and the number of fir advance growth.

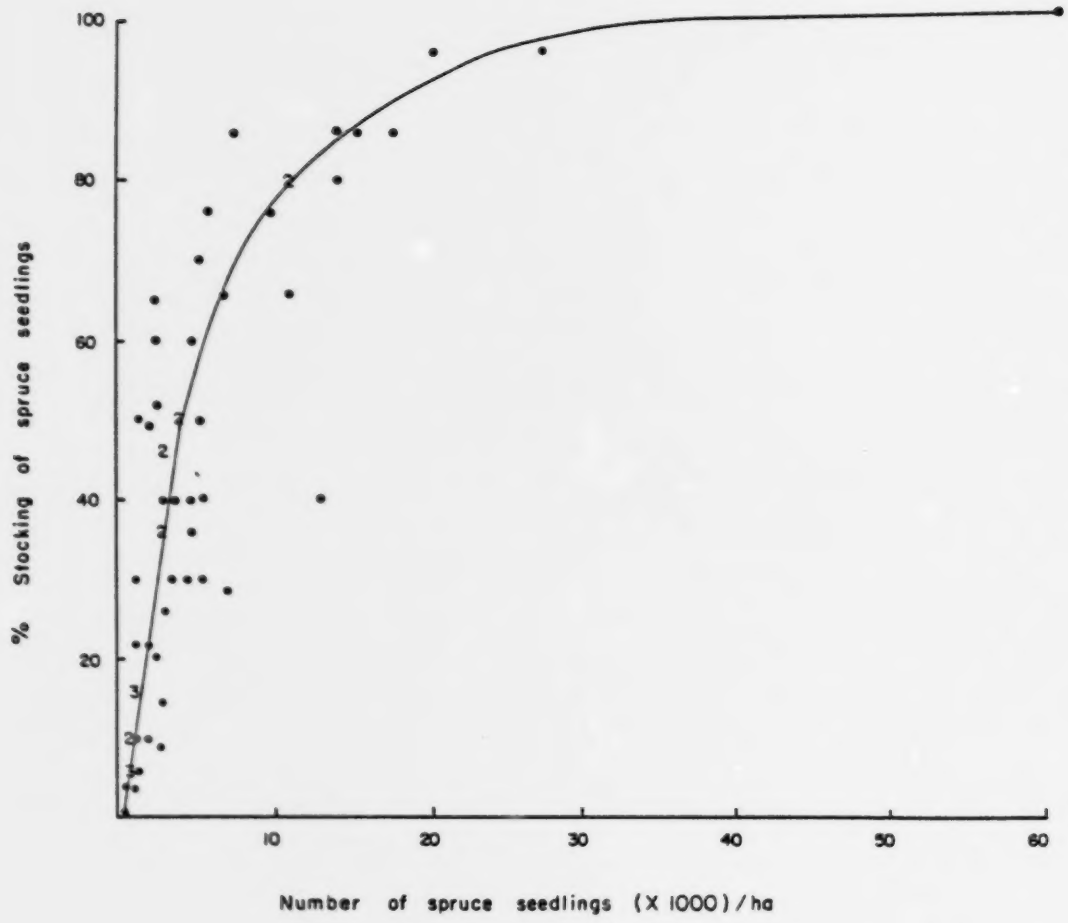

Figure 6. Relationship between the percent stocking and the number of spruce advance growth.

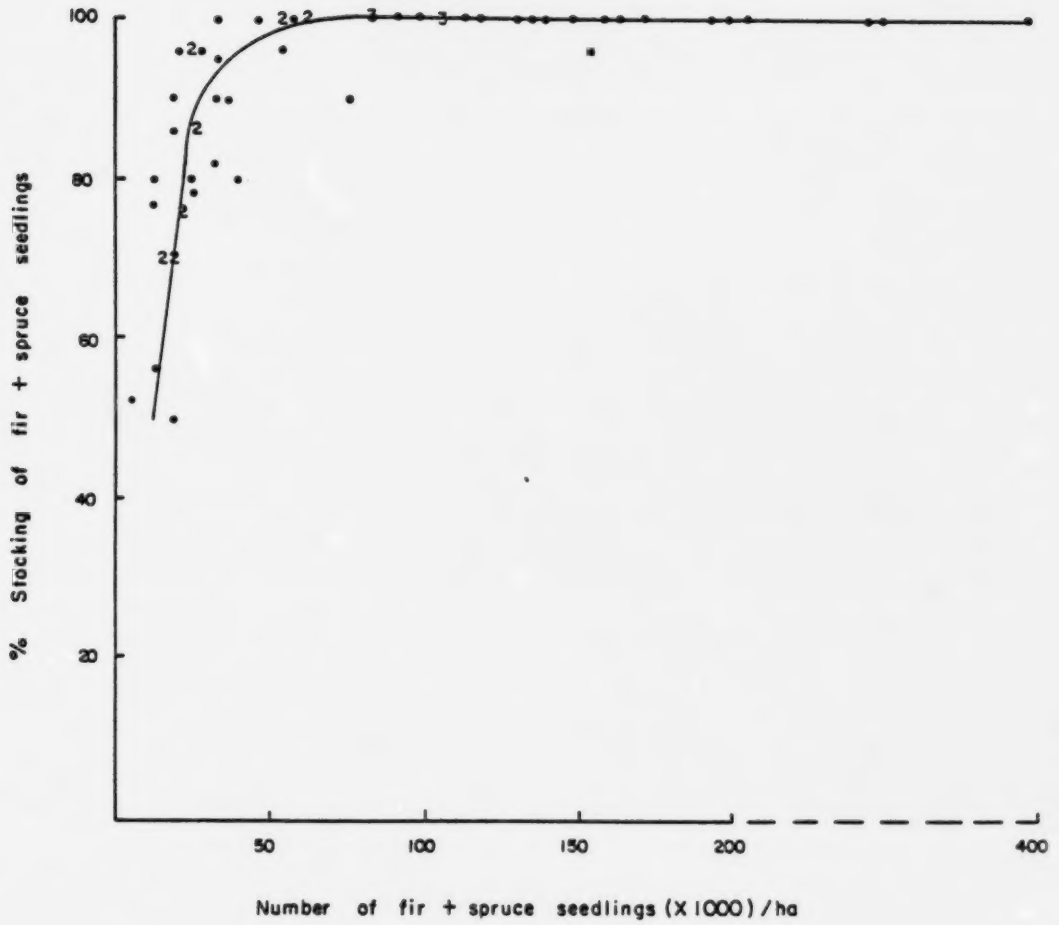

Figure 7. Relationship between the percent stocking and the number of fir and spruce advance growth combined.

approximately 200 to 60,000 seedlings/ha (Fig. 4a).

The low advance growth densities associated with a low spruce or conversely a high fir component, appear to be largely a result of the competition from the shrubs and ferns that dominate the understory vegetation. As well, hardwood overstory densities were commonly in the range of 20 to 40%, thereby contributing considerable leaf litter that could easily smother small softwood seedlings.

With high percentages of spruce in the overstory, there is an accompanied change in the understory vegetation. A transition occurs from the domination of shrubs such as mountain maple, striped maple, hazel and raspberry to a largely ericaceous cover. As well, hardwood densities in the overstory were considerably lower than in the fir dominated stands. Fir advance growth densities increase only slightly (Fig. 3a) but a sharp increase occurs in the densities of spruce advance growth (Fig. 4a). This greater increase for spruce may be influenced by the availability of seed. Overall, the higher densities suggest that more favourable conditions exist on the spruce sites for the germination and survival of the softwood advance growth.

Group 2 Stands

These stands have by far the highest numbers of advance growth. In contrast to the low density stands (Group 1), these higher density stands show decreasing numbers of fir advance growth with increasing percentages of spruce in

the overstory (Fig. 3b). The spruce advance growth shows a similar trend to the low density stands of increasing densities with an increasing percentage of spruce in the overstory (Fig. 4b).

The greatest differences in the advance growth between Group 1 and Group 2 stands occurs with the higher percentages of fir in the overstory. With > 50% spruce, more similar ranges for both fir and spruce advance growth occur in the 2 groups. In comparing the understory vegetation, the greatest differences also occur in the fir dominated stands. The Group 2 stands are characterized by an understory of ferns, herbs and mosses with ericaceous (largely vaccinium) vegetation commonly present. Shrubs such as mountain maple, striped maple, hazel and raspberry that dominate the Group 1 stands are not common. It is likely, that competition from the understory vegetation for the germination and survival of the fir and spruce advance growth is much less in the Group 2 stands than in the Group 1 stands. In the spruce dominated stands however, there is less of a difference in the understory vegetation between the 2 groups which also corresponds to more similar advance growth patterns. Ericaceous vegetation is most common in both groups.

The highest densities of fir advance growth (up to 381,000/ha) are associated with pure fir stands (> 90% of the total stand composition being fir) having very even canopies. Considerable variations in advance growth densi-

ties may occur with small changes in stand composition and structure although the numbers do not generally fall below 100,000/ha (Fig. 3b).

For stands with >10% spruce, the decreases in fir advance growth densities become more gradual as the percentage of spruce increases (Fig. 3b). From 10% to 50% spruce, the advance growth densities range from 150,000 down to 50,000. With >50% spruce in the overstory, densities are mainly between 50,000 and 20,000 seedlings/ha.

Spruce advance growth densities range from approximately 100/ha for stands with 100% fir to approximately 18,000/ha for stands with 100% spruce (Fig. 4b).

Group 3 Stands

The lowest densities of advance growth are associated with Group 3 stands. This group has a number of variations of stand conditions. Included are:

1) Two storied fir-spruce stands with an overstory of scattered 100 year old+ spruce and a dense understory of fir resulting from the 1913-1919 spruce budworm outbreak.
2) Fir-spruce stands that had selective cutting, possibly 30 to 50 years ago. As a result of this cutting, advance growth was released and formed dense patches of nonmerchantable suppressed trees.
3) High density, small diameter black spruce stands on predominantly imperfectly to poorly drained sites.

The stands sampled with a high fir content (Figs. 3c and 4c) are those described by conditions 1 and 2. The proportion of nonmerchantable stems in these stands is often very patchy which may contribute to a high variability in advance growth densities. Advance growth is largely absent under these patches.

The stands with >80% spruce are black spruce stands described by condition 3 above. The greatest occurence of these stands is in the lowland region (Fig. 1, Area 3). Advance growth densities (Figs. 3c and 4c) associated with these stands can be expected to be low. The high stand densities may limit factors such as light and temperature which are important in the successful establishment of fir and spruce (Place, 1955). In addition, the imperfectly to poorly drained condition associated with these stands do not create favourable seedbeds. On the patches of sphagnum moss which are common on these sites, fir or spruce seedlings are rarely found.

POSTCUT CONDITIONS

Origins of the Fir and Spruce Regeneration

Of the 1534 fir seedlings and the 1360 spruce seedlings randomly selected from the cutovers and aged, 86% and 85%, respectively, were of advance growth origins. Similar percentages of advance growth have also been found in cutovers in the northeastern United States (Westveld, 1931),

Quebec (Hatcher, 1960) and New Brunswick (Vincent, 1956).

Of the 14% and 15% of the seedlings that were not advance growth, only 1% of the fir and 1% of the spruce actually seeded-in after cutting. The remaining seedlings were found to be the same age as the cut (=) or 1 year younger (-1) than the age of the cut (Table 1a). Where the seedlings were the same age as the cut, the seed had been released the previous year and germinated the year the cut was made. For seedlings 1 year younger than the cut, the seed was released the same year as the cut and germinated the following year.

Table 1b gives a further breakdown of the cutovers where seedlings other than those of advance growth origins were found. For seedlings that were 1 year younger or equal to the age of the cut, it was found for fir that the highest percentages occurred in 1979 and 1980 cuts, respectively. This corresponds to a heavy seed year for fir in 1979 (personal communication, N. Kreiberg -DFME). Spruce shows a less obvious pattern of seedling establishment. No seed years were recorded for spruce from 1977 to 1981 (personal communication, N. Kreiberg - DFME).

As some fir and spruce seed is generally produced each year (Fowells, 1965), seedlings were also found to establish in the cutovers without the influence of a seed year. For black spruce, there may also be some carry-over of seed as the semiserotinous cones may contain viable seed for several years (Fowells, 1965). In cutovers where seedlings

Table 1. Origins of the fir and spruce regeneration in the cutovers.

a. All seedlings

No. Cutovers Sampled = 80	No. Fir Seedlings Measured = 1534	No. Spruce Seedlings Measured = 1360	
	% FIR	% SPRUCE	
Seedlings that were older than the age of the cut (+)	86	85	(advance growth)
Equal to the age of the cut (=)	8	10	(from seed released year prior to the cut)
One year younger than the age of the cut (-1)	5	4	(from seed released same year as the cut)
Two or more years younger than the age of the cut (-2+)	1	1	(seeded-in)

b. Percent of the cutovers (1) and the percent of the seedlings in those cutovers (2) where regeneration other than advance growth was found.

Year Cut	1978		1979		1980		1981	
No. Cutovers Sampled	11		17		29		23	
	(%)		(%)		(%)		(%)	
	Fir	Spruce	Fir	Spruce	Fir	Spruce	Fir	Spruce
Equal to the age of the cut (=)	45(1)	45(1)	29	59	69	62	30	39
	13(2)	11(2)	13	12	24	21	7	20
One Year younger than the age of the cut (-1)	54	36	41	65	31	41	-	-
	8	11	30	13	12	11	-	-
Two or more years younger than the age of the cut (-2+)	54	45	12	18	7	3	-	-
	6	8	10	5	5	10	-	-

established during the year of cutting (=) or the following year (-1), averages of 11% of the fir and 14% of the spruce were found to be of these origins (Table 1b). Seeding-in (-2+) also occurred in some cutovers, however, the amounts were smaller with averages of 7% of the fir and 8% of the spruce being found (Table 1b).

Although some association was made between the degree of seedling establishment and the availability of seed, more difficulty occurs in attempting to define the conditions under which this postcut establishment is likely to occur. Approximately 50% of the cutovers were found to have seedlings that established the year of the cut or the following year (Table 1b). For these cutovers, there were no clear relationships with the year of cutting or the harvesting system. However, if seedling establishment occurred, both fir and spruce were generally found in a cutover. This suggests that some precise conditions of harvesting were met that were favourable for the germination and survival of both fir and spruce. For example, it is speculated that harvesting before the germination of the seed has occurred (by early July) would favour the establishment of new germinants the same year as the cut. The seedlings may have a better chance of adjusting to the environment as they germinate in the cutover as compared to the shock of the overstory being removed after germination. As well, seedlings would not be lost in the harvesting operation. For seedlings to establish the year after

the cut, the most favourable conditions would likely result from fall cuttings which occur after the seed has ripened in the cones. Seed may enter the cutovers on the slash or have been released in the stand before harvesting. Westveld (1931) has also stated that where new seedlings establish, this is likely to occur within the first 2 years following cutting. Although he attributes this to favourable seed-bed conditions produced by the logging operation, evidence here also suggests that the timing of harvesting and the availability of seed are strong influences.

Although the amount of seeding-in did not increase in the cutovers with an increase in the period of time since harvesting, there was a progressive increase in the percentage of the cutovers in which these seedlings were found (Table 1b). With the distance of effective seed dispersal for fir and spruce generally being less than 100 m (Baker, 1950; Fowells, 1965), the amount of seed entering a cutover can be expected to diminish rapidly in moving away from the forest edge. However, over time, small amounts may randomly filter into an increasing number of cutovers with high winds or possibly by rodents.

Although the postcut establishment of fir and spruce seedlings is on average relatively insignificant in relation to the number from advance growth, in some cases the decision to plant may be influenced. Of the cutovers that were below adequate softwood stocking (<60%) with only the

surviving advance growth, 25% showed ≥60% stocking[1] after seedling establishment had occurred. These changes in stocking levels all occurred within one summer after harvesting and as well, most were in relation to the 1979 seed year for fir.

Predicting the Postcut Fir and Spruce Regeneration

In presenting the fir and spruce regeneration patterns, only seedlings that are of advance growth origins will be included. The total densities of fir and spruce seedlings in each cutover were adjusted by the percentages of advance growth that were obtained from the ageing of the seedlings. This adjustment was made in order to relate the patterns of advance growth before harvesting to the survival after harvesting.

As discussed previously, predicting the addition of seedlings to the cutovers appears to require more information related to seed production and precise conditions of harvesting. At this time, those seedlings, which generally form only a small percentage of the regeneration (Table 1) only add unexplained variation to the analyses and require further study to be incorporated.

Plot Pairs

The method of plot pairing was used to assess the effect of harvesting and the season of cut on the fir and

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1 ≥60% softwood stocking is accepted as adequate for fir-spruce and spruce-fir cover types

spruce advance growth. The comparison of skidder and forwarder operations is shown for fir in Figures 8a and 8b (curves are hand-fitted) and for spruce in Figures 9a and 9b (curves are hand-fitted). Group 2 and Group 3 stands are included. Each sample point represents a stand average. Tree-length and full-tree operations have been combined because of a limited number of full-tree operations. As well, there is a strong weight on summer cuts. Only 4 winter cuts were sampled and they were all shortwood Koehring operations (forwarder). Winter cuts have been excluded from the relationships shown in Figures 8 and 9.

Overall, the general trend is for higher precut densities to result in higher postcut densities of fir and spruce advance growth. Winter cuts showed higher seedling survival with the differences between summer and winter cuts being slightly greater for fir than for spruce (Figs. 8b and 9b).

For summer cuts, fir survival was found to be lower for skidder than forwarder operations (Figs. 8a and 8b). The average survival rates for the 2 operations were 13% and 21%, respectively. This difference is given as an average because there was a decrease in the survival of balsam fir from low to high advance growth densities. For skidder operations, the survival rates decreased from 20% to 9% for corresponding precut densities of 25,000 to 150,000 seedlings/ha. For forwarder operations, the rates were slightly higher but the same trend followed with sur-

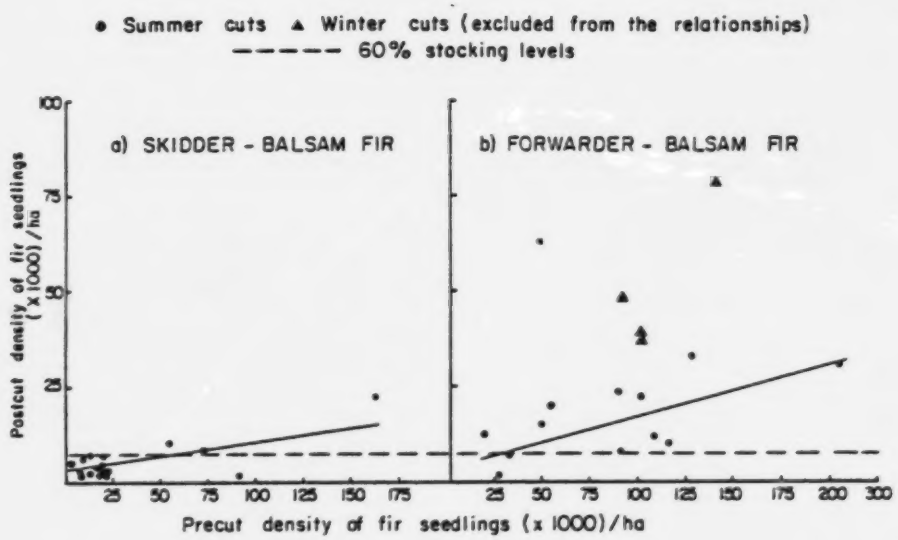
• Summer cuts ▲ Winter cuts (excluded from the relationships)
60% stocking levels
a) SKIDDER - BALSAM FIR
b) FORWARDER - BALSAM FIR
Postcut density of fir seedlings (x 1000)/ha
Precut density of fir seedlings (x 1000)/ha

Figure 8. Survival of fir advance growth after skidder and forwarder operations as determined from the plot pairs.

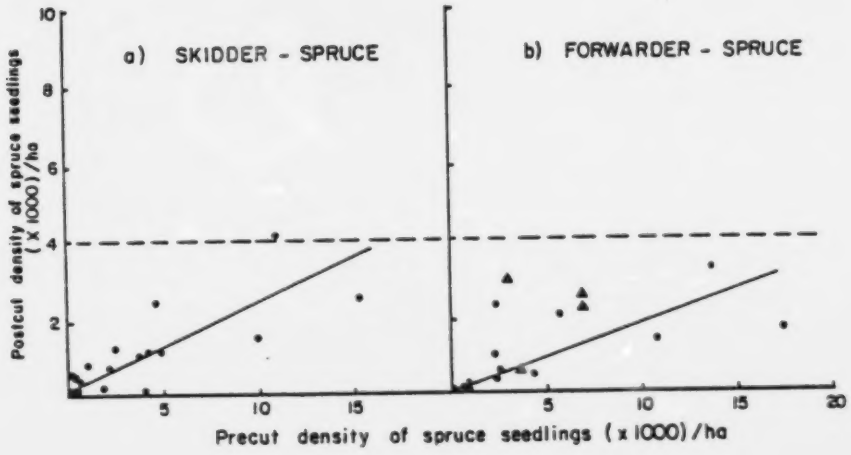
a) SKIDDER - SPRUCE
b) FORWARDER - SPRUCE
Postcut density of spruce seedlings (x 1000)/ha
Precut density of spruce seedlings (x 1000)/ha

Figure 9. Survival of spruce advance growth after skidder and forwarder operations as determined from the plot pairs.

vival decreasing from 29% to 16% for increasing precut densities of 25,000 to 150,000 seedlings/ha.

The survival of spruce for summer cuts shows different patterns than those for balsam fir. There were smaller differences in the survival rates for spruce between skidder and forwarder operations (Figs. 9a and 9b). In fact, skidder operations showed a slightly higher survival of 24% compared to 18% for forwarder operations. The patterns for spruce also differed from fir in that less change occurred in the survival rates from low to high precut densities.

Relationships to the Precut Stand

Densities of postcut fir and spruce advance growth are presented in relation to the precut stand composition in Figures 10 to 13 (curves are hand-fitted). Each sample point represents a stand average. Precut advance growth densities have been superimposed from Figures 3 and 4 for comparison. Skidder and forwarder operations are presented with full-tree and tree-length operations again being combined. All cuts were made in the summer so no comparisons of the seasons could be made. As with the plot pairs, the adjustment from the ageing data was made to include only those seedlings that were of advance growth origin.

The cutover plots have, like the uncut stands, been grouped by their original precut densities. Stand densities for the cutovers were determined from a tally of the stumps and residual stems. Only cutovers from Group 1 and Group 2 were available.

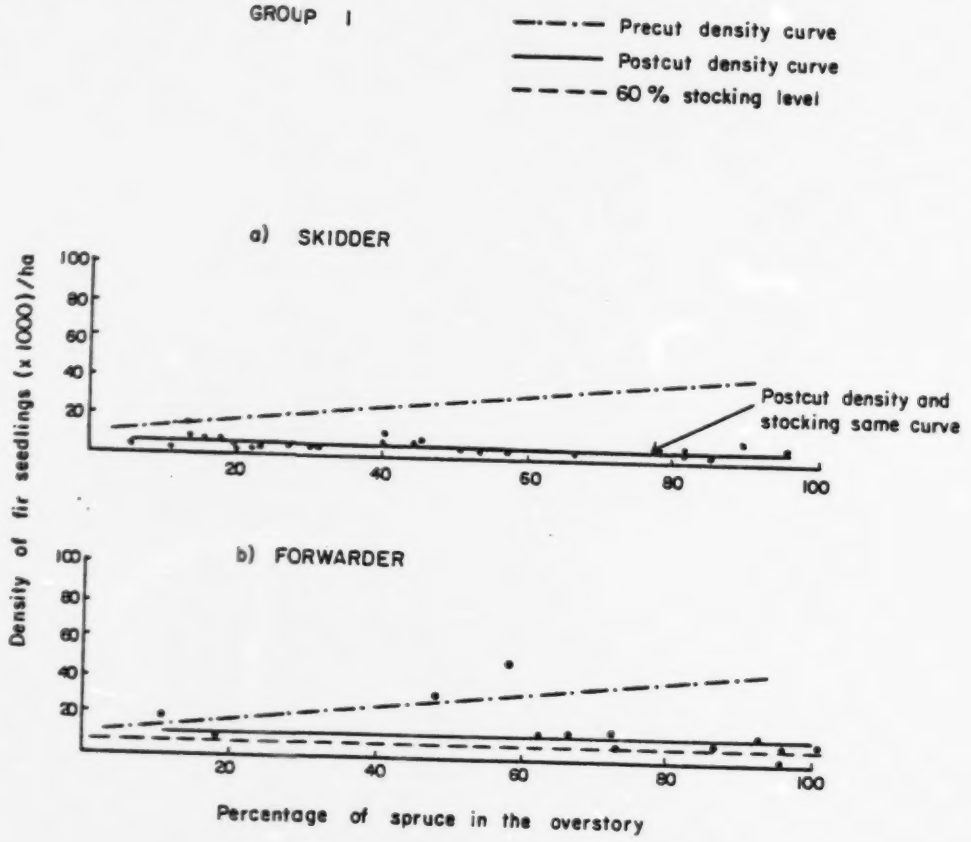

Figure 10. Survival of fir advance growth after skidder and forwarder operations for Group 1 stands.

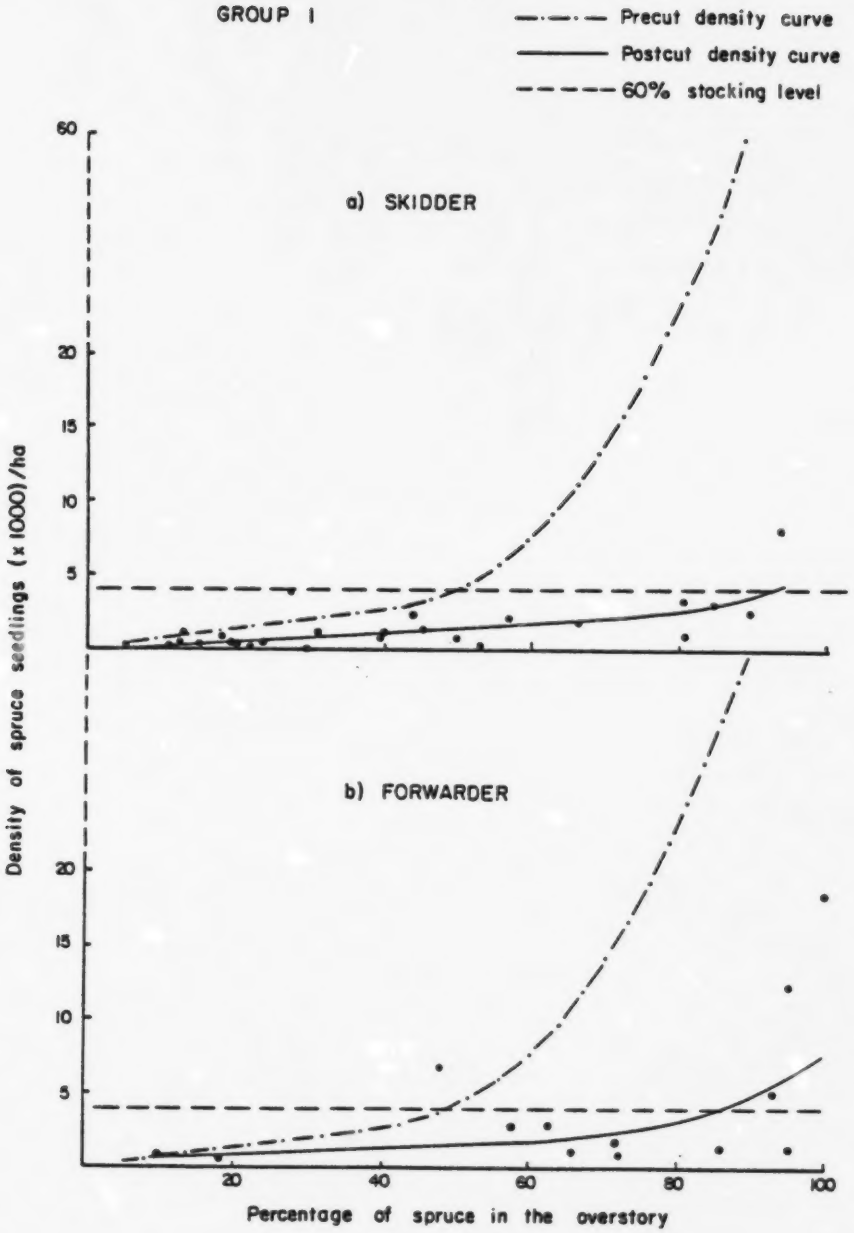

Figure 11. Survival of spruce advance growth after skidder and forwarder operations for Group 1 stands.

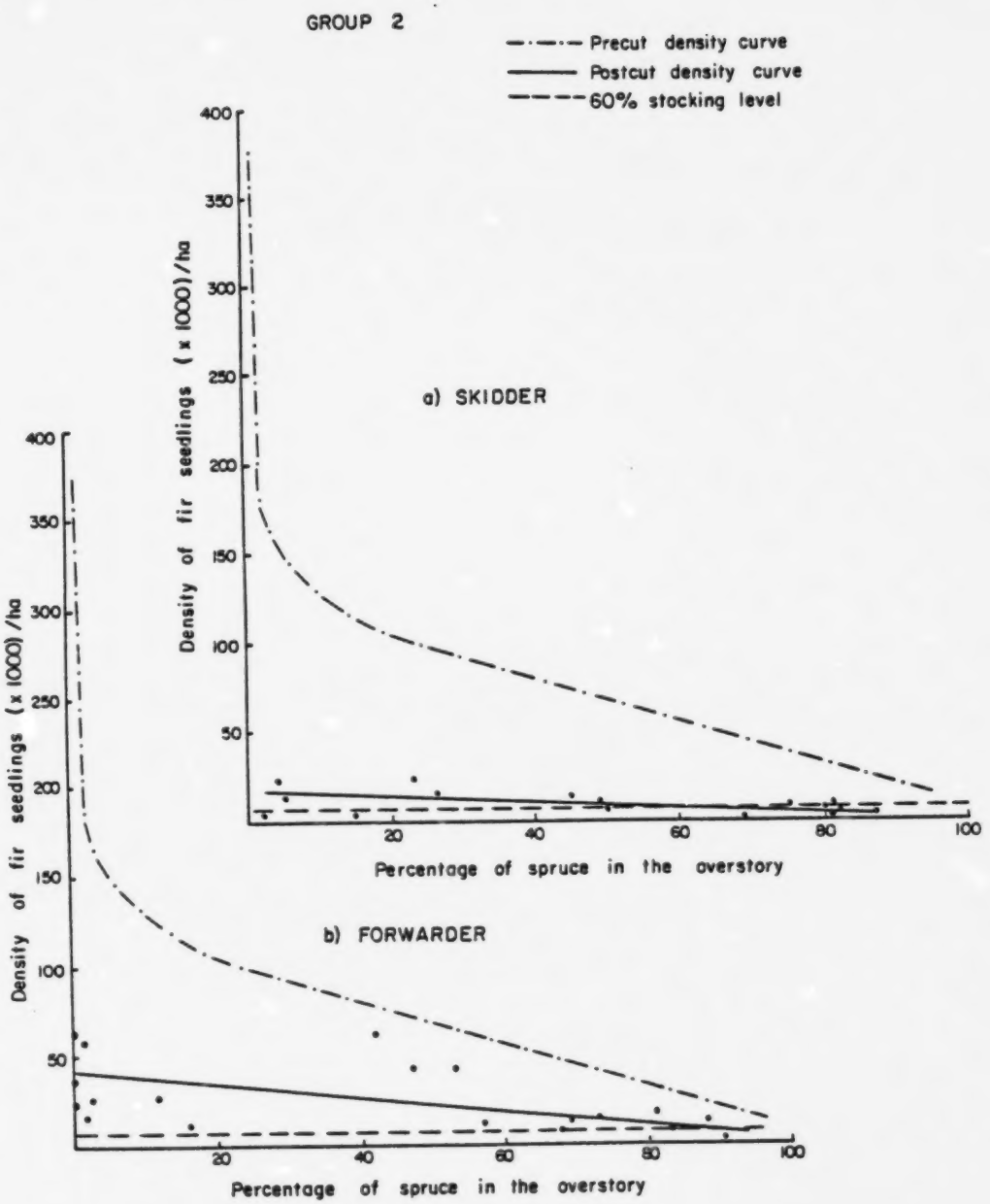

Figure 12. Survival of fir advance growth after skidder and forwarder operations for Group 2 stands.

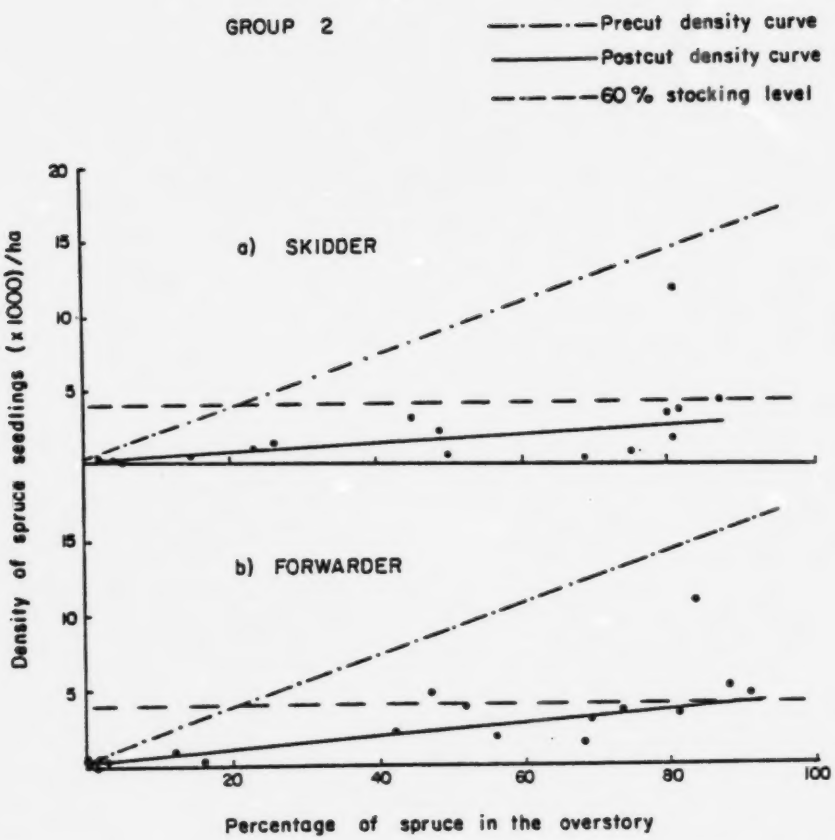

Figure 13. Survival of spruce advance growth after skidder and forwarder operations for Group 2 stands.

The link between the precut and postcut densities of fir and spruce advance growth is further supported by the patterns shown in Figures 10 to 13. Although postcut densities are considerably lower, similar trends to the precut overstory-advance growth relationships occur. Higher precut densities generally result in higher postcut densities although the steepest parts of the precut curves become considerably flattened in the postcut condition. The general pattern of decreasing survival with increasing precut densities is exhibited. As with the plot pairs, the highest mortality of seedlings occurs for high density fir which is associated with Group 2 stands having an almost pure fir overstory (Fig. 12). As well, higher survival rates were found to coincide with lower precut densities.

Comparisions between skidder and forwarder operations also showed some similar patterns to the plot paris. For balsam fir, forwarder operations showed higher survival rates than skidder operation for both groups of stands. In Group 1, similar precut densities resulted in average postcut survival rates of 22% and 40% for skidder and forwarder operations, respectively (Figs. 10a and 10b). For Group 2 stands the average survival rates were 11% and 31% for skidder and forwarder operations, respectively (Figs. 12a and 12b).

Spruce also, as in the plot pairs, shows more similarity in survival patterns than fir for skidder and forwarder operations. The average survival rates for skidder and

forwarder operations respectively, were 27% and 31% for Group 1 stands (Figs. 11a and 11b) and 18% and 26% for Group 2 stands (Figs. 13a and 13b). These patterns however, show some variation in comparison to the plot pairs where skidder operations resulted in slightly higher survival than forwarder operations. With such small differences in survival in both methods of study as well as considerable overlap of the data, it is difficult to draw any firm conclusions in relation to the impact of the 2 harvesting systems. The key in Appendix I (pg. 62) has however, been developed from Figures 11 and 13 because of greater sampling intensity over a wider range of precut advance growth densities. In particular, the better representation of samples in the higher density ranges ($> 10,000$) may give more reliability to the conclusions drawn from this method of study as it generally follows that the greatest differences between the harvesting systems occur with the higher precut densities. Further testing is required however, to verify the predictions.

The differences in survival patterns between skidder and forwarder operations may be somewhat related to the precut distribution patterns of the seedlings. Balsam fir at high densities typically establishes under a forest canopy in a clumped distribution (Godin, 1982). As advance growth densities decrease, there is an associated decrease in clumping until a more scattered distribution occurs (Godin, 1982).

With the greatest differences in survival rates between skidder and forwarder operations occurring for the highest densities of fir advance growth (Group 2 stands), it is suggested that the clumping of fir may be a strong contributing factor. Skidder operations have been observed to almost completely destroy large clumps of fir in the skid trails whereas forwarders are able to pass over the seedlings causing considerably less damage. In contrast, the least differences in mortality between skidder and forwarder operations occur for the lowest precut densities which also have a more scattered distribution pattern. The loss of seedlings in the skid trails would comprise a much lower percentage of the total mortality when the seedlings are scattered.

As well as the clumping pattern of the seedlings possibly influencing the survival, the sizes of seedlings may also have a considerable effect. The relationships between seedling densities and height distributions were found to be similar to those described by Godin (1982). At the highest densities (largely fir), the majority of the seedlings were in height class 1 ($\leq$ 15 cm). These seedlings may be subject to a high mortality from desiccation as they are generally very shallowly rooted in the duff layer which may dry out following harvesting. As densities decrease, the clumps of small seedlings diminish and there is an increase in the average seedling height. These larger seedlings also have a better developed root system and would

likely suffer less from desiccation. The general pattern of higher mortality with higher seedling densities may be related to the combined effects of clumping and desiccation. Other studies have also shown greater logging damage to occur with higher seedling densities (Vincent, 1956; Frisque et al., 1978).

Relationships Between the Postcut Density and Stocking Levels of Fir and Spruce

The relationships between the postcut densities and stocking levels are presented for fir, spruce and fir and spruce combined in Figures 14 to 16, respectively. Each sample point represents a stand average. If acceptable stocking levels for softwood cutovers are taken to be $\geq$ 60%, postcut densities of approximately 7500 fir (Fig. 14) or 7500 fir and spruce combined (Fig. 16) would be required. For spruce alone, 60% stocking is reached at approximately 4000 seedlings/ha (Fig. 15).

The 60% stocking levels are shown in Figures 10 to 13 for comparison to the postcut density patterns. Table 2 gives a summary of the percent of the cutovers in each stand group that had $\geq$60% and $\geq$40% stocking levels after skidder and forwarder operations. The stocking levels for the surviving advance growth alone are compared to those that result when seedlings that established postcut are included. Corresponding to the low percentages of seedlings that establish postcut (Table 1) the changes in stocking

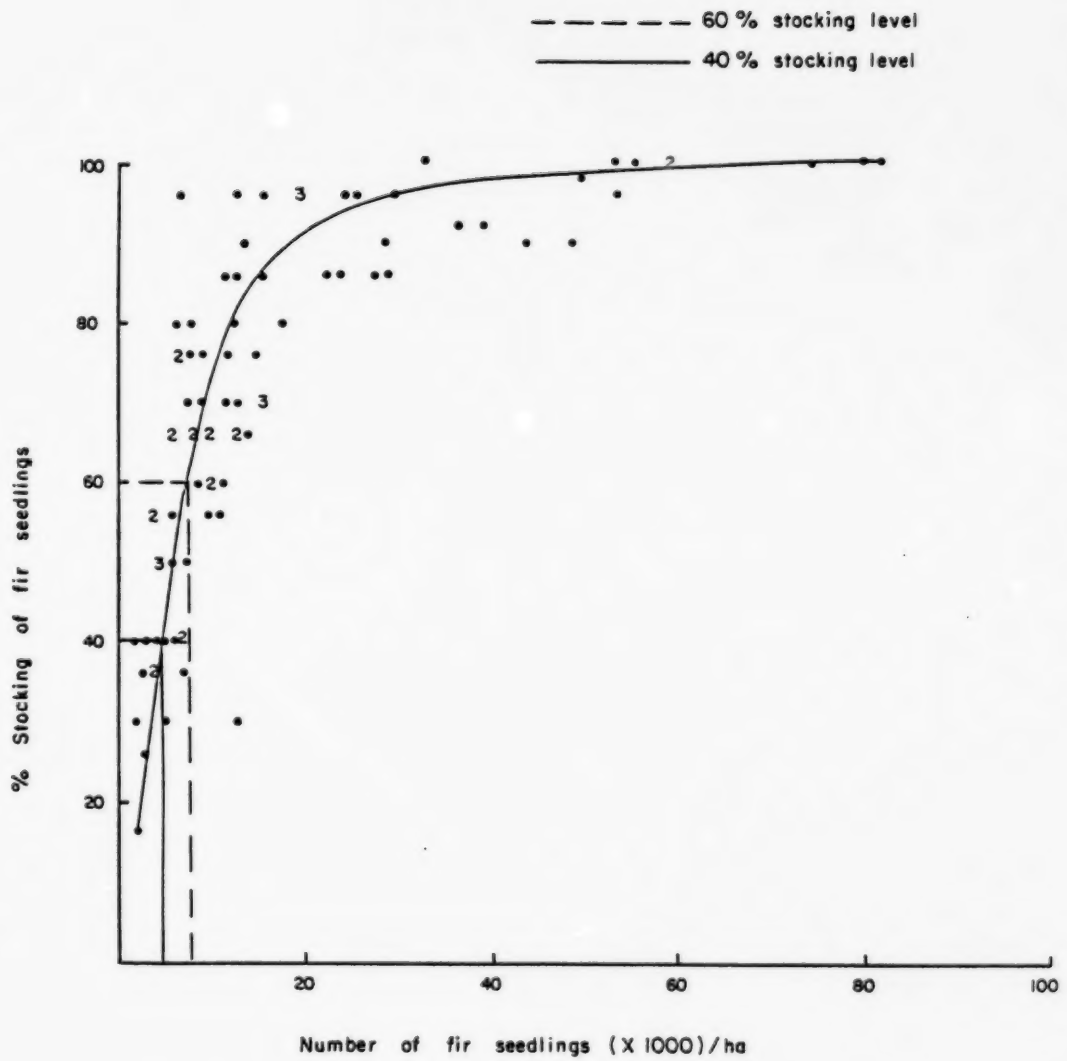

Figure 14. Relationship between the percent stocking and the number of fir seedlings in the cutovers.

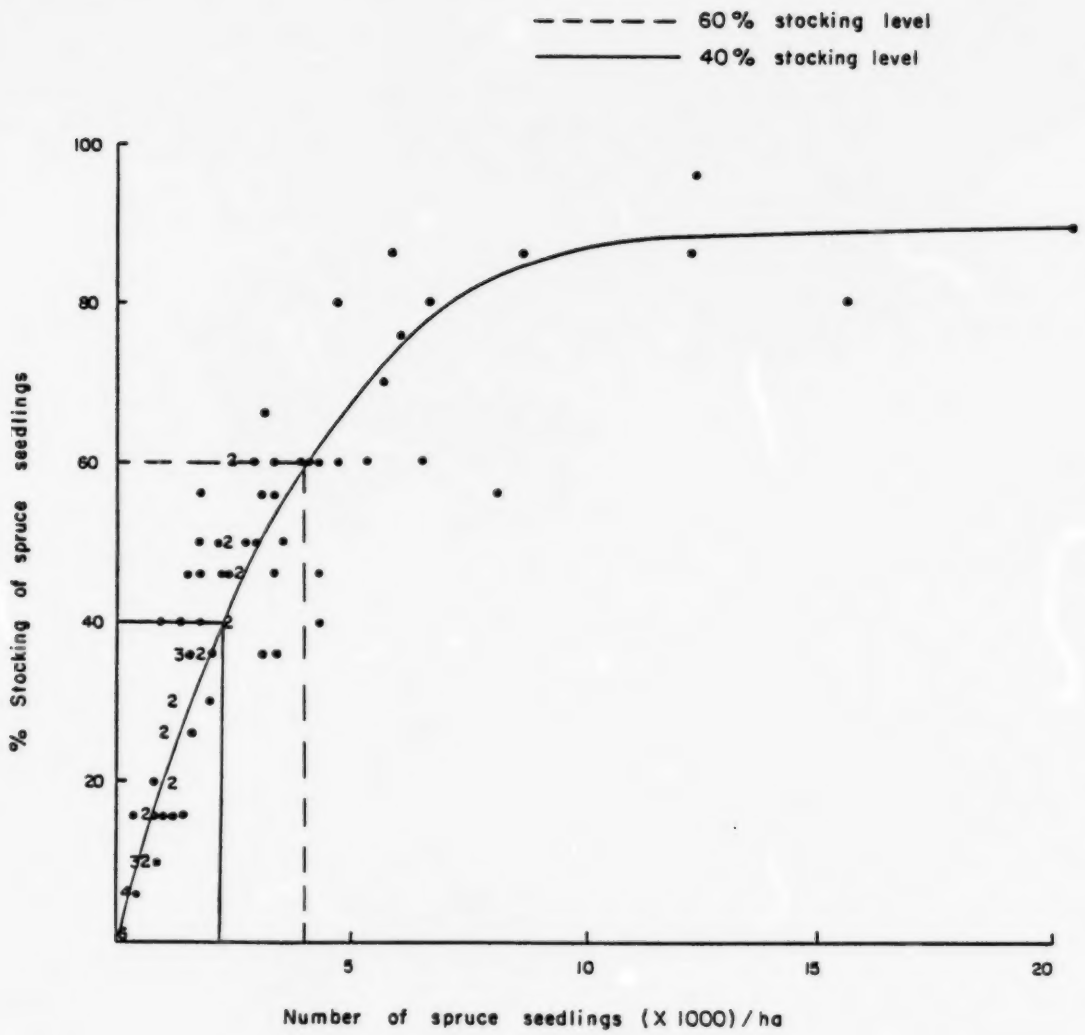

Figure 15. Relationship between the percent stocking and the number of spruce seedlings in the cutovers.

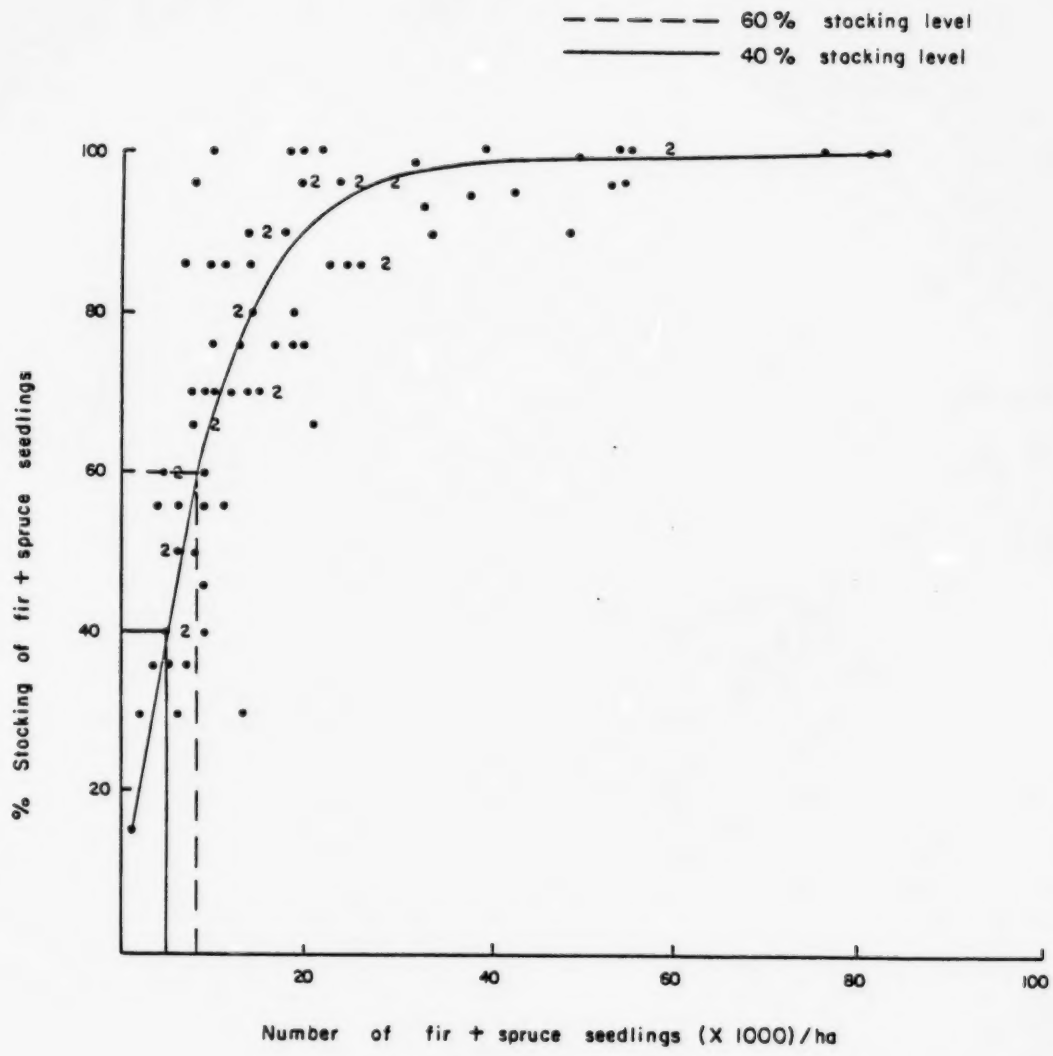

Figure 16. Relationship between the percent stocking and the number of combined fir and spruce seedlings in the cutovers.

Table 2. Percent of the cutovers having ≥ 60% and ≥ 40% stocking of fir and spruce after skidder and forwarder operations. Percentages are calculated from the surviving advance growth alone (1) and with the inclusion of seedlings that established after harvesting (2).

	% Cutovers with ≥ 60% Stocking						% Cutovers with ≥ 40% Stocking					
	Skidder			Forwarder			Skidder			Forwarder		
		Fir & Spruce	Spruce		Fir & Spruce	Spruce		Fir & Spruce	Spruce		Fir & Spruce	Spruce
1. GROUP 1 STANDS												
Percent Spruce in the Overatory	No. Cut-overs			No. Cut-overs			No. Cut-overs			No. Cut-overs		
20	8	50[1] (50)[2]	0 (0)	2	100 (100)	0 (0)	8	50 (62)	0 (0)	2	100(100)	0 (0)
20-40	7	29 (57)	0(14)	0	- -	- -	7	71 (71)	14 (29)	0	- -	- -
40-60	5	40 (60)	0 (0)	2	100 (100)	50(50)	5	60 (80)	20 (40)	2	100(100)	100(100)
60-80	1	0 (0)	0 (0)	4	100 (100)	0 (0)	1	0 (0)	0 (0)	4	100(100)	25 (50)
80-100	5	80 (80)	20(20)	5	80 (100)	60(60)	5	100(100)	80 (80)	5	80(100)	60 (80)
Average		40 (49)	4 (7)		95 (100)	28(28)		56 (63)	23 (30)		95(100)	46 (58)
2. GROUP 2 STANDS												
20	4	50 (50)	0 (0)	8	100 (100)	0 (0)	4	50(100)	0 (0)	8	100(100)	0 (0)
20-40	2	100 (100)	0 (0)	-	- -	- -	2	100(100)	0 (50)	-	- -	- -
40-60	3	33 (67)	0 (0)	4	100 (100)	25(50)	3	100(100)	67(100)	4	100(100)	50 (75)
60-80	2	50 (50)	0 (0)	3	100 (100)	0 (0)	2	50 (50)	0 (0)	3	100(100)	67 (67)
80-100	5	40 (60)	40(60)	4	75 (75)	75(75)	5	80(100)	80 (80)	4	100(100)	100(100)
Average		55 (65)	8(12)		94 (94)	25(31)		76 (90)	29 (46)		100(100)	54 (60)

levels were also low (Table 2).

Corresponding to the lower postcut densities (Figs. 10 to 13), skidder operations also resulted in lower percentages of cutovers with $\geqslant$ 60% stocking of softwood regeneration (fir and spruce) as compared to forwarder operations. On average, only 50% of the cutovers had adequate softwood stocking ($\geqslant$ 60%) after skidder operations whereas almost 100% of the cutovers were adequately stocked after forwarder operations.

The variability in adequate stocking for skidder operations shows some relationship to the percentage of spruce in the overstory. Group 1 stands show an increasing possibility of reaching 60% stocking with an increasing spruce content (Figs. 10a and 11a, Table 2). For Group 2 stands, combining the reverse patterns of decreasing densities of fir (Fig. 12a) and increasing densities of spruce (Fig. 13a) with an increase in the percentage of spruce in the overstory has a tendency to produce a more uniform distribution of the cutovers having $\geqslant$ 60% stocking over the range of spruce contents in the overstory (Table 2).

For spruce alone, the percentages of cutovers with $\geqslant$ 60% stocking are considerably lower than for fir and spruce combined (Table 2). However, as the spruce content in the overstory increases, the correspondingly higher postcut densities of spruce result in higher percentages of cutovers with $\geqslant$ 60% stocking. Forwarder operations also show higher percentages than skidder operations as a result

of the higher postcut densities (Figs. 11 and 13), however, this difference as discussed previously requires further study.

The patterns for $\geqslant 40\%$ stocking are similar to those for $\geqslant 60\%$ with slightly higher increases in the percentages of cutovers having this stocking level. Postcut densities of approximately 5000 fir (Fig. 14), 5000 fir + spruce (Fig. 16) and 2200 spruce (Fig. 15) are required for 40% stocking.

Postcut Hardwoods and Shrubs

As many hardwoods and shrubs may present considerable competition for the fir and spruce seedlings, forecasting their establishment in cutovers would provide useful information for planning herbicide and cleaning operations. However, considerably more difficulty was encountered in attempting to define the factors that determine the occurrence and levels of the hardwoods and shrubs.

Although raspberry, white birch and pincherry were found to be the dominant species on the well-drained sites (Area 1, Area 2, Fig. 1), it is difficult to predict which of these will dominate and if the cover will be sufficient to cause mortality and reduced vigour of the softwood seedlings. In the lowlands (Area 3, Fig. 1), the situation is slightly less complex as ericaceous vegetation is dominant on the poorly drained sites and the competition level is generally low. However, problems may be encountered with

very slight rises in elevation as raspberry commonly invades on these better drained areas.

To develop a system of forecasting hardwood and shrub regeneration, detailed study is required to define the complex of interactions that result in the successful dispersal, germination and survival of the invading species. Although site features such as drainage, soil fertility, slope, aspect or climate likely have a strong influence, the response patterns may be further complicated by such factors as the ground distubance from the harvesting operation, time of harvesting, slash distribution, seed years and proximity to seed sources (particularly for hardwoods), vegetative reproduction or the overstory composition.

The level of detail available from this study was found to be inadequate for the development of such a forecasting system. With the sampling techniques used in this study, details of the harvesting disturbance and the precise conditions at the time of harvesting could not be obtained. As well, information pertaining to the availability of seed was not available. Although cooperation was undertaken with the DFME Site Classification Group to obtain detailed site information, these data could not be used to link the patterns of hardwood and shrub establishment to the site conditions. However, some of these data from the cutovers in Area 1 are being analysed by a senior forestry student with particular emphasis on the changes in the vegetation communities from the uncut to the cutover

condition. To obtain an understanding of the interaction of the factors that control hardwood and shrub establishment, it is recommended that further study is concentrated on the conditions at the time of harvesting and during the immediate postharvest period.

In conclusion, the following precut- postcut trends were established for several fir-spruce and spruce-fir cover types throughout central and northern New Brunswick:

1. Postcut fir and spruce densities are largely dependent on the precut advance growth densities which are linked to the composition and structure of the overstory.
2. Relationships occur between the densities and stocking of both the precut and postcut fir and spruce seedlings.
3. Forwarder operations result in higher survival rates than skidder operations for balsam fir advance growth.
4. Although it is suggested, that forwarder operations result in slightly higher survival rates than skidder operations for spruce advance growth, further study is required to verify this conclusion.
5. In general, seedling survival decreases with increasing precut advance growth densities.

RECOMMENDATIONS FOR FURTHER STUDY

The system for forecasting cutover response in the fir-spruce and spruce-fir cover types is at this time still in the preliminary stages because of the limited data base and inadequate testing to date. Although trends have been established between the conditions of the uncut stand, the harvesting system and the cutover response, further data are required to identify more specifically the factors involved and therefore better define the variability in the present system.

The methodologies used in this study presented some problems for examining the details of the system. With both the plot pairs and the stump and residual tallies, it was only possible to make assumptions about the densities and therefore stocking of the total precut softwood advance growth and as well, the percentages of spruce advance growth. As the advance growth is strongly tied to the total densities of the overstory fir and spruce and the proportions of fir to spruce, the accuracy is only as good as the ability to obtain this precut stand data. Some problems were encountered in both systems.

In the plot pairing, an attempt was made to check the potential error in photo interpretation by the measurement of the stumps and residuals in the paired cutovers. However, this checking may be affected by a second source of error which relates to the ability to obtain total fir and

spruce densities from the stump and residual tallies. This error, as well, may affect the second method of study where stump and residual tallies alone were used to link the precut and postcut conditions.

Although it was not possible to determine completely the accuracies of the methodologies, some conclusions may be drawn from the plot pairing. As a correlation exists between the uncut and the cutover densities of the merchantable fir and spruce (Fig. 17) it is concluded that there was reasonable accuracy in the pairing and the tallies of the stumps and residuals. It is noted however, that the stem tallies in the cutovers were generally lower than the uncut stems. This may be due to missing stems in the cutover tally or to differences in the methods of sampling in the uncut stands and the cutovers. A similar pattern also exists for the merchantable spruce (Fig. 18) which is an important factor in predicting the advance growth.

As the relationships between the overstory and the advance growth are dependent on the total stand densities of the fir and spruce, it is also important to obtain accurate estimates of the nonmerchantable stems. This is where the major source of error appears to occur. Considerably more difficulty was encountered in the pairing or the tally in the cutovers of the nonmerchantable fir and spruce as no correlation exists between the uncut and cutover tallies (Fig. 19). As these stems often occur in the understory, plot pairing may be difficult from air photos. As well,

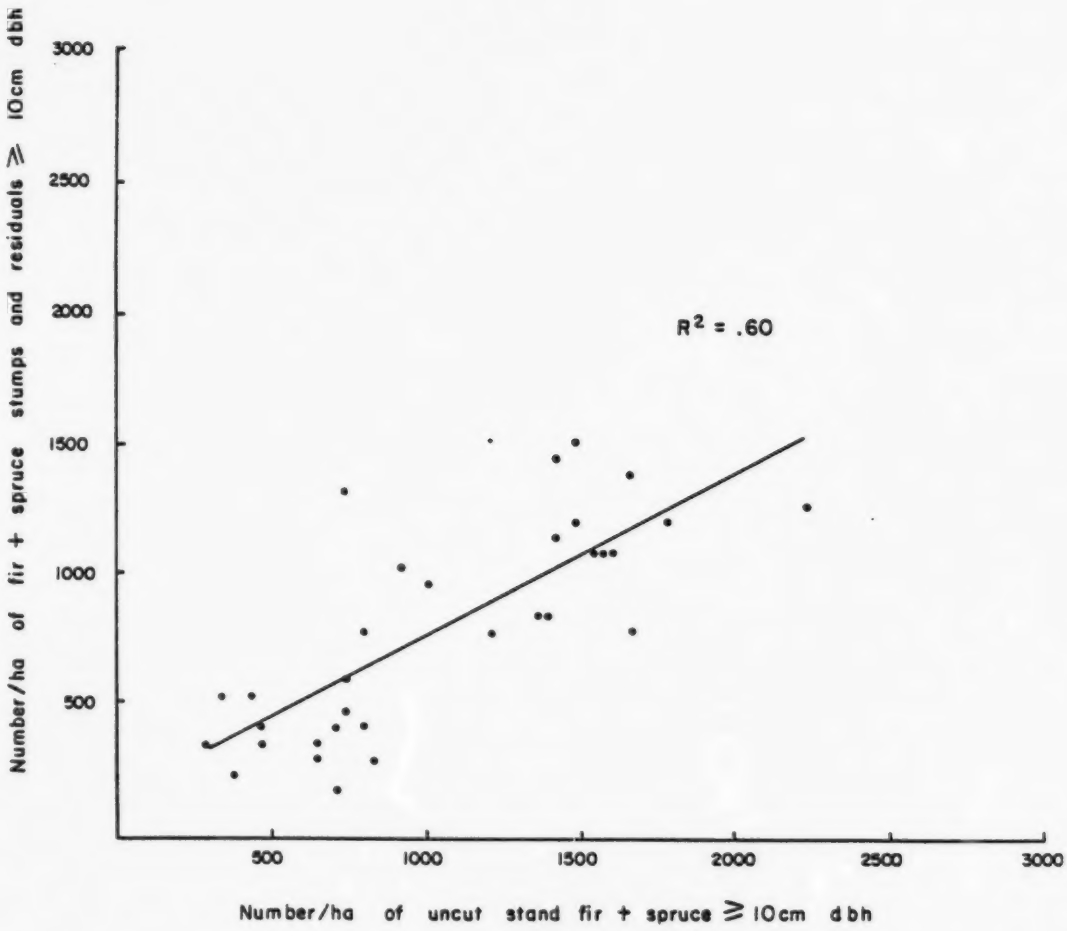

Figure 17. Accuracy in matching the merchantable overstory fir and spruce in the plot pairs.

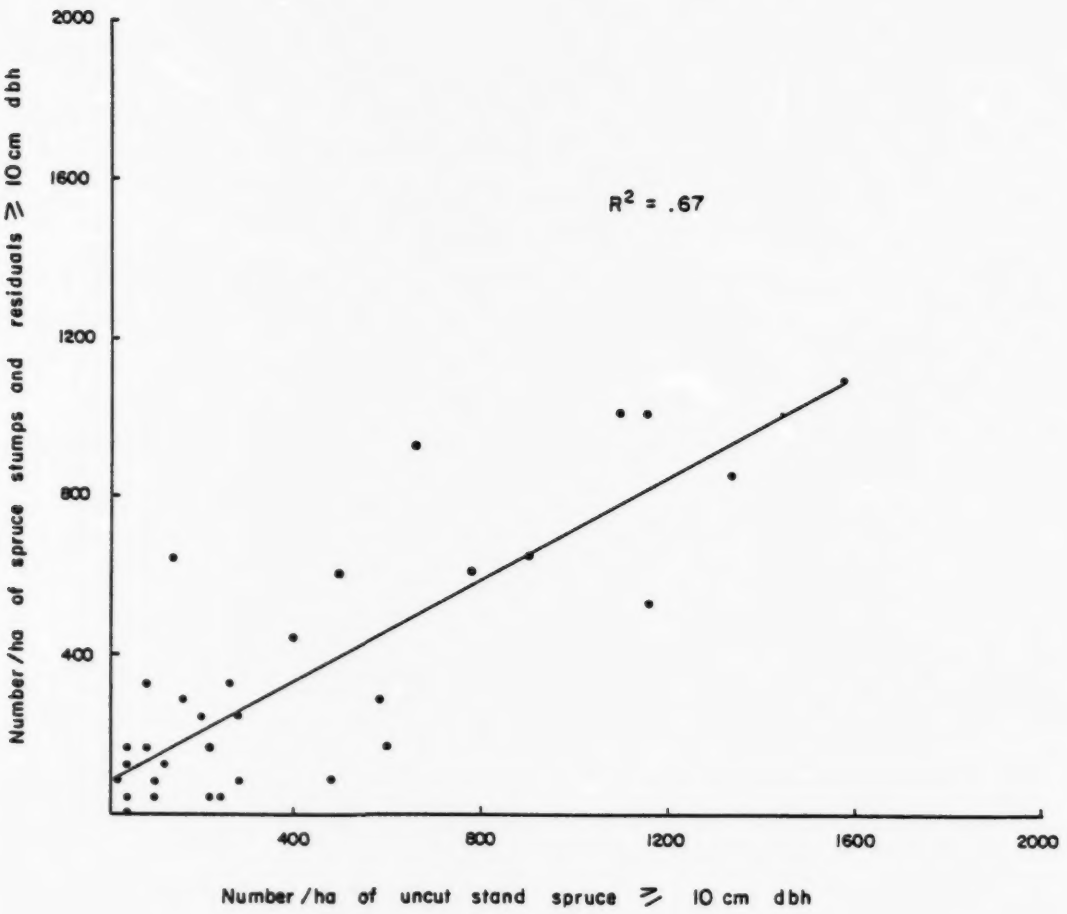

Figure 18. Accuracy in matching the merchantable overstory spruce in the plot pairs.

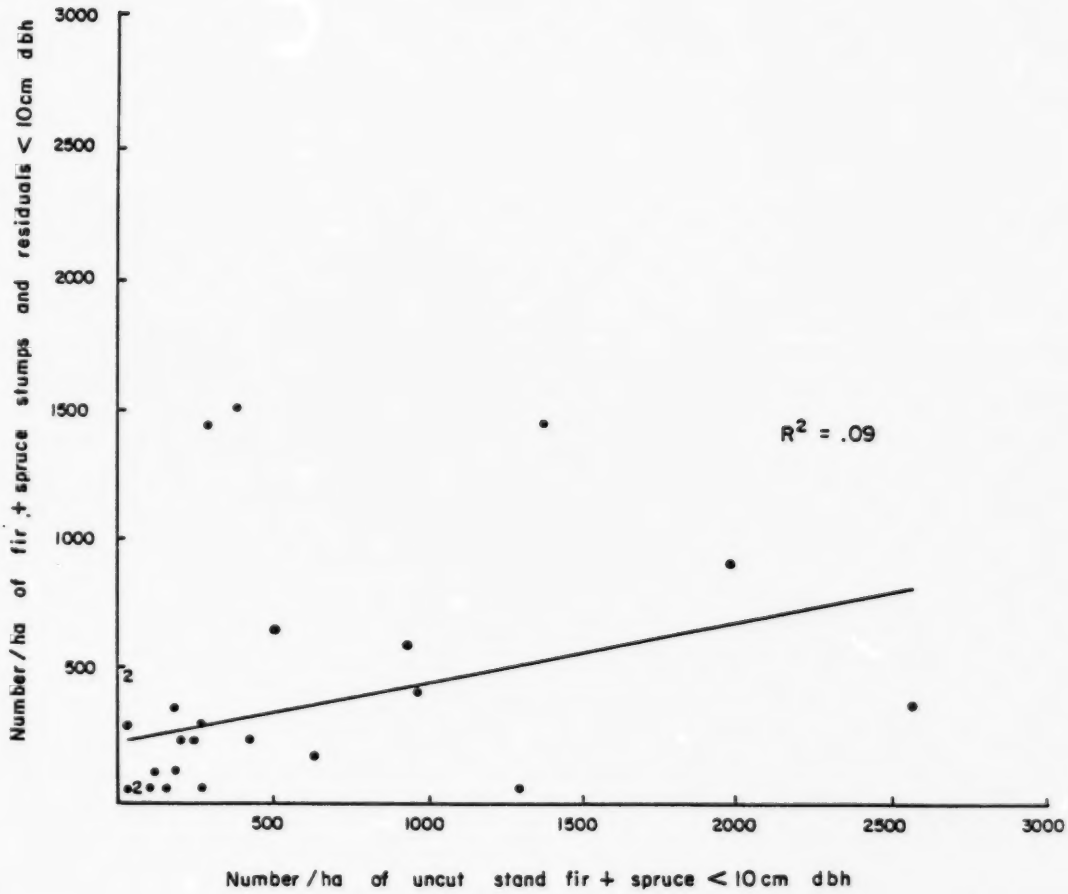

Figure 19. Accuracy in matching the nonmerchantable overstory fir and spruce in the plot pairs.

accurate tallies in the cutovers may be affected by these stems often being totally crushed in the harvesting operation.

As well as problems being associated with the accuracies of the sampling methods, details are lost in directly linking the precut data to the conditions at approximately 5 years after harvesting. Little possibility exists to separate the factors that may contribute to the cutover response patterns. As further study should be aimed at defining these details in the system, it is not recommended that either of the methods be used.

As an alternative, it is suggested that data be collected through a system of sampling stands that are to be harvested in current operating plans and to follow immediately with a postcut sampling. As well as the precut sampling providing additional data and testing of the precut overstory-understory relationships, combined with an immediate postcut sampling it would be possible to define more specifically the impacts of various harvesting systems on the survival of the advance growth under specific conditions.

In addition to defining the impact of the harvesting system, it is recommended that sampling be carried out to assess the degree of seedling desiccation which is expected to be the second major cause of mortality. As the greatest exposure to the seedlings likely occurs during the first summer after harvesting, this second assessment should fol-

low after this period. As well as defining the impact of exposure, data may also be provided in this sampling to define further the conditions that favour the establishment of fir and spruce either the same year as the cut or the following year.

Since small increases in the densities and therefore stocking of fir and spruce have been found to occur from seeding-in, there appears to be little requirement for study beyond one full summer after harvesting. Reliable predictions of this initial cutover response should provide adequate information to make decisions for site preparation and planting.

As well as a precut-postcut sampling system providing more accurate forecasting of the softwood regeneration, details pertaining to the establishment of the hardwoods and shrubs may also be assessed. Although hardwood and shrub densities change considerably over time, this assessment one year after harvesting would likely indicate the dominant species and a relative competition level.

In addition to further sampling being required to test and refine the present keys (Appendix I) efforts should concentrate on expanding the guide to include the major forest cover/site conditions and harvesting systems.

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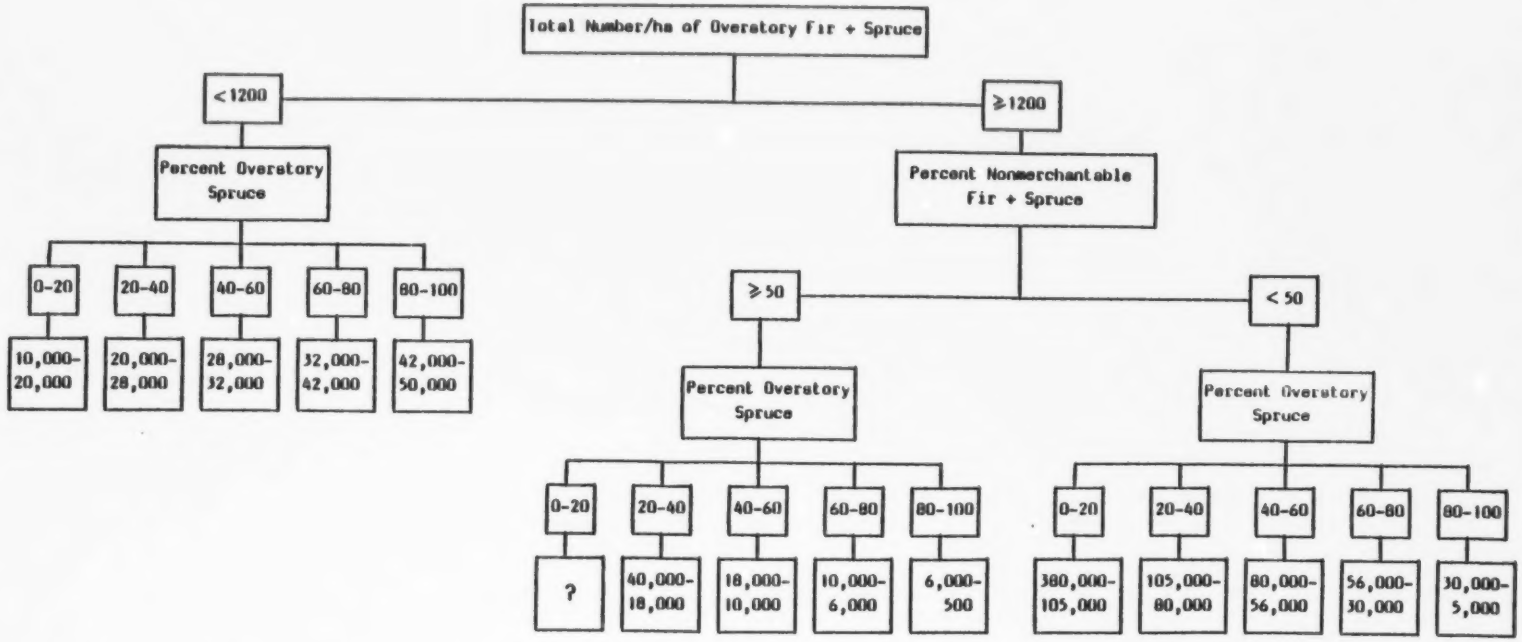
APPENDIX I

PRELIMINARY FIELD GUIDE TO FORECASTING CUTOVER RESPONSE FOR FIR-SPRUCE AND SPRUCE-FIR STANDS

KEY FOR DETERMINING NUMBER/HA OF PRECUT FIR ADVANCE GROWTH

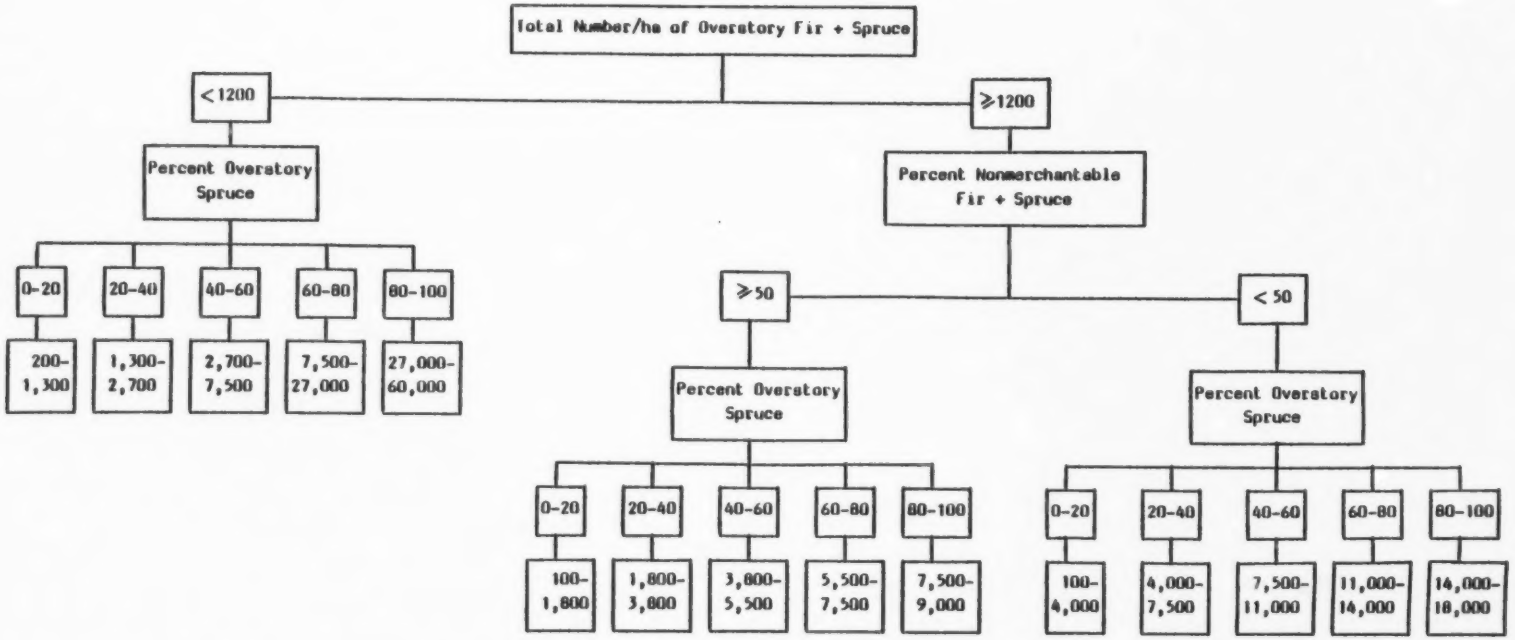


Total number/ha of overstory fir + spruce = Nonmerchantable (2-8 cm dbh) + merchantable (≥ 10 cm dbh) stems

Percent overstory spruce = (Number/ha of merchantable spruce / Number/ha of merchantable fir + spruce) x 100

Percent nonmerchantable fir + spruce = (Number/ha of nonmerchantable fir + spruce / Total number/ha of overstory fir + spruce) x 100

KEY FOR DETERMINING NUMBER/HA OF PRECUT SPRUCE ADVANCE GROWTH

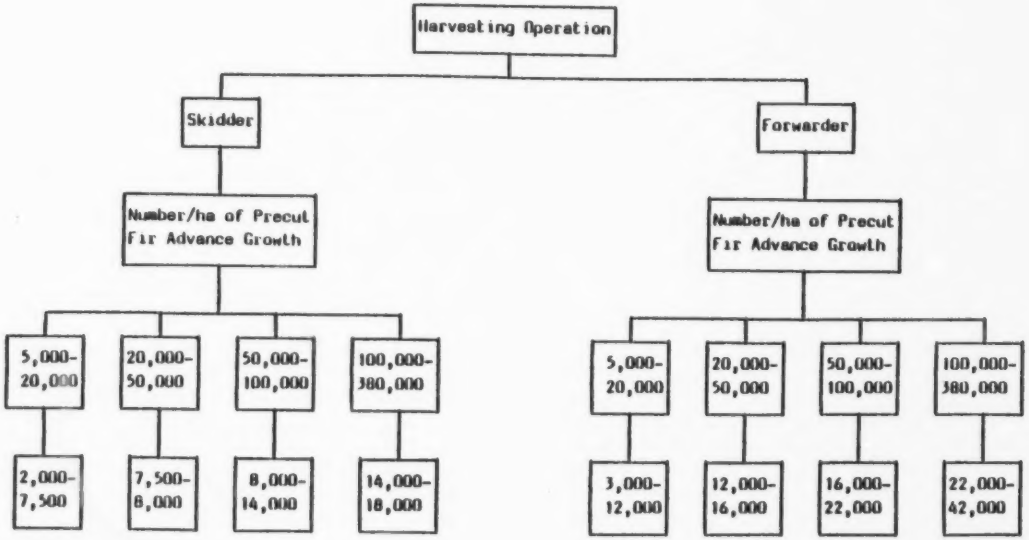


Total number/ha of overstory fir + spruce = Nonmerchantable (2-8 cm dbh) + merchantable (≥ 10 cm dbh) stems

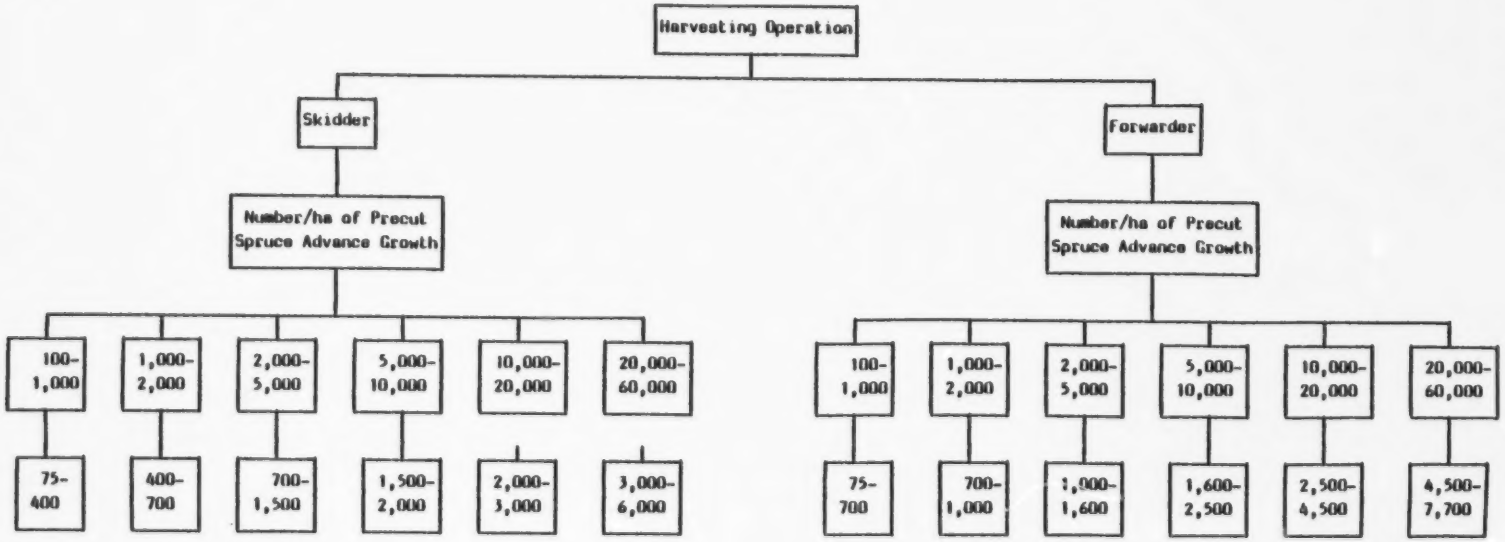
Percent overstory spruce = (Number/ha of merchantable spruce / Number/ha of merchantable fir + spruce) x 100

Percent nonmerchantable fir + spruce = (Number/ha of nonmerchantable fir + spruce / Total number/ha of overstory fir + spruce) x 100

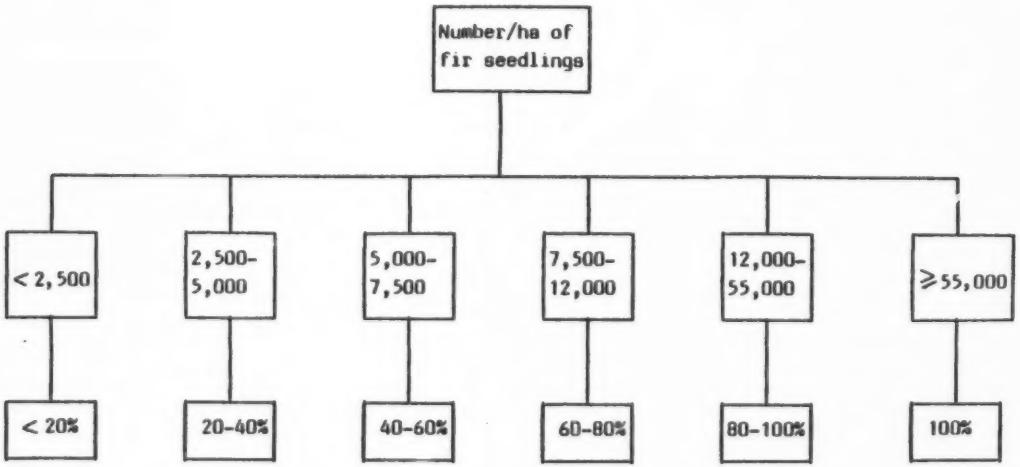
KEY FOR DETERMINING NUMBER/HA OF SURVIVING
FIR ADVANCE GROWTH AFTER SUMMER HARVESTING



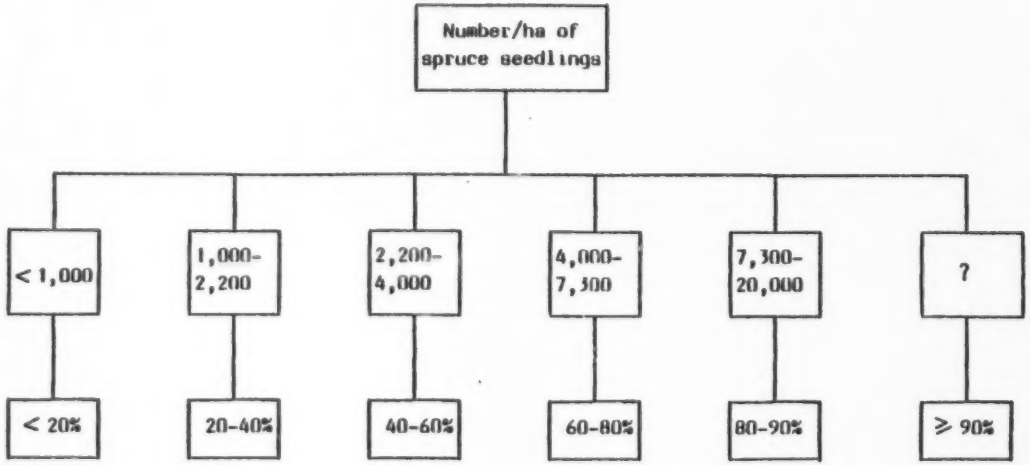
KEY FOR DETERMINING NUMBER/HA OF SURVIVING
SPRUCE ADVANCE GROWTH AFTER SUMMER HARVESTING



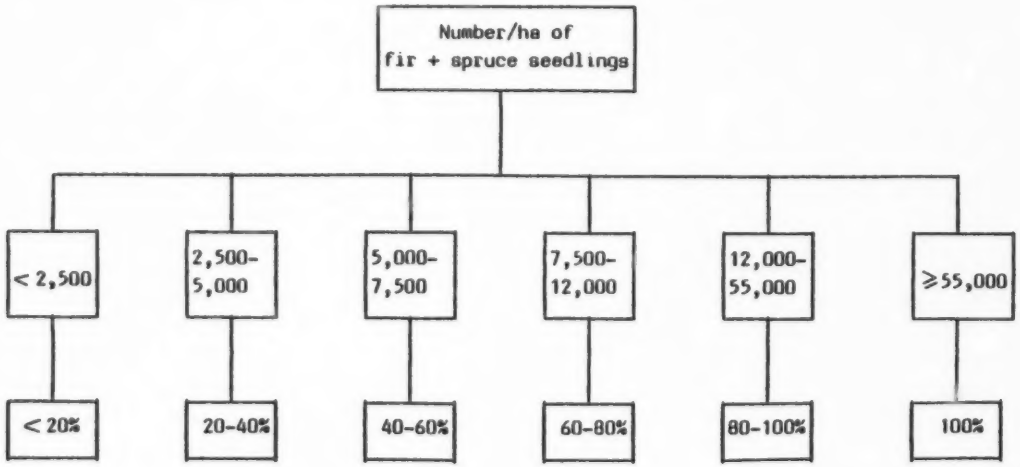
KEY FOR DETERMINING % STOCKING
OF FIR SEEDLINGS (ADVANCE GROWTH +VOLUNTEER REGENERATION)
IN A CUTOVER



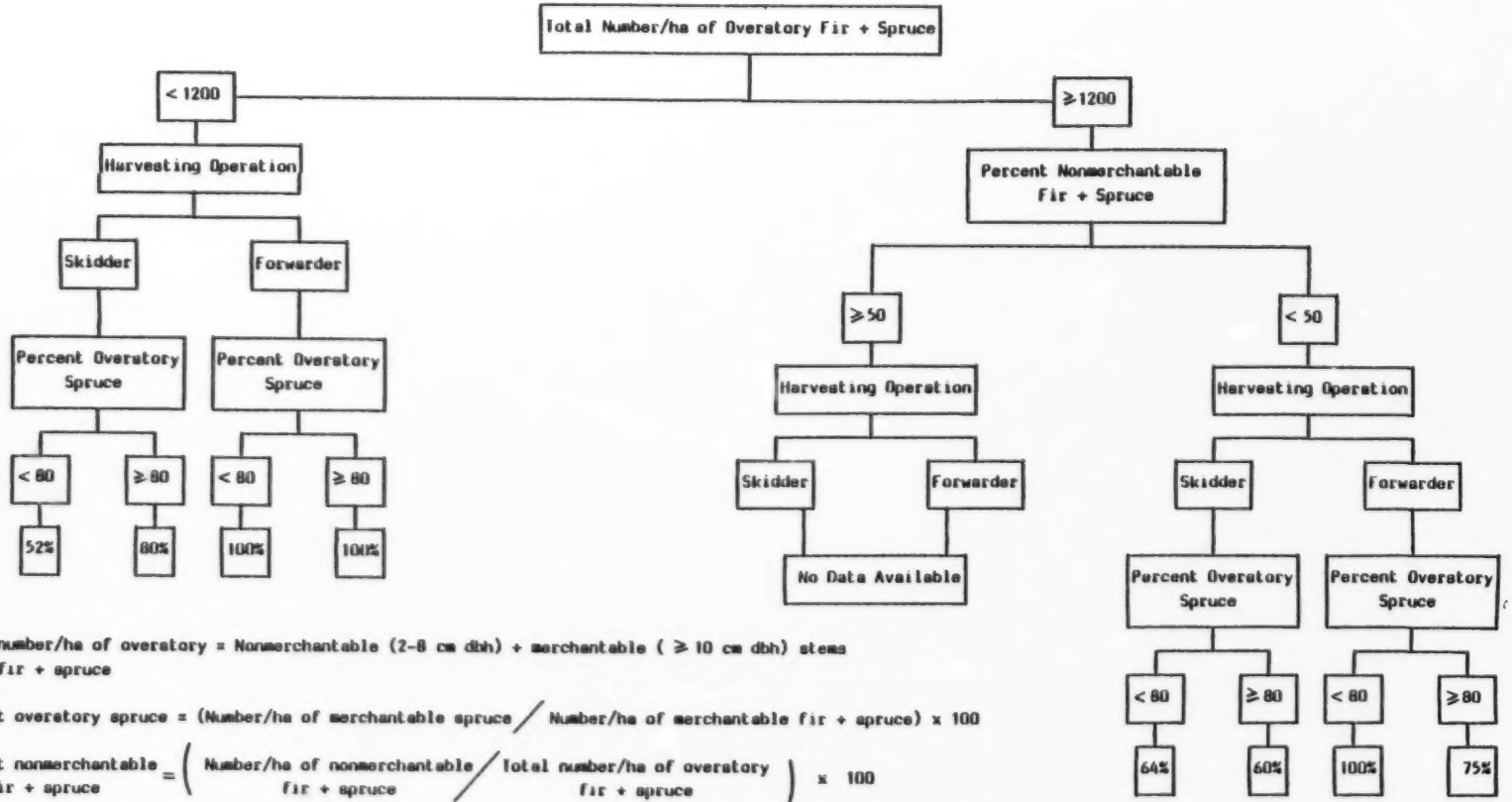
KEY FOR DETERMINING % STOCKING
OF SPRUCE SEEDLINGS (ADVANCE GROWTH +VOLUNTEER REGENERATION)
IN A CUTOVER



KEY FOR DETERMINING % STOCKING
OF FIR + SPRUCE SEEDLINGS (ADVANCE GROWTH +VOLUNTEER REGENERATION)
IN A CUTOVER



KEY FOR DETERMINING PROBABILITY OF HAVING ≥60% POSTCUT STOCKING OF FIR + SPRUCE (ADVANCE GROWTH + VOLUNTEER REGENERATION) AFTER SUMMER HARVESTING

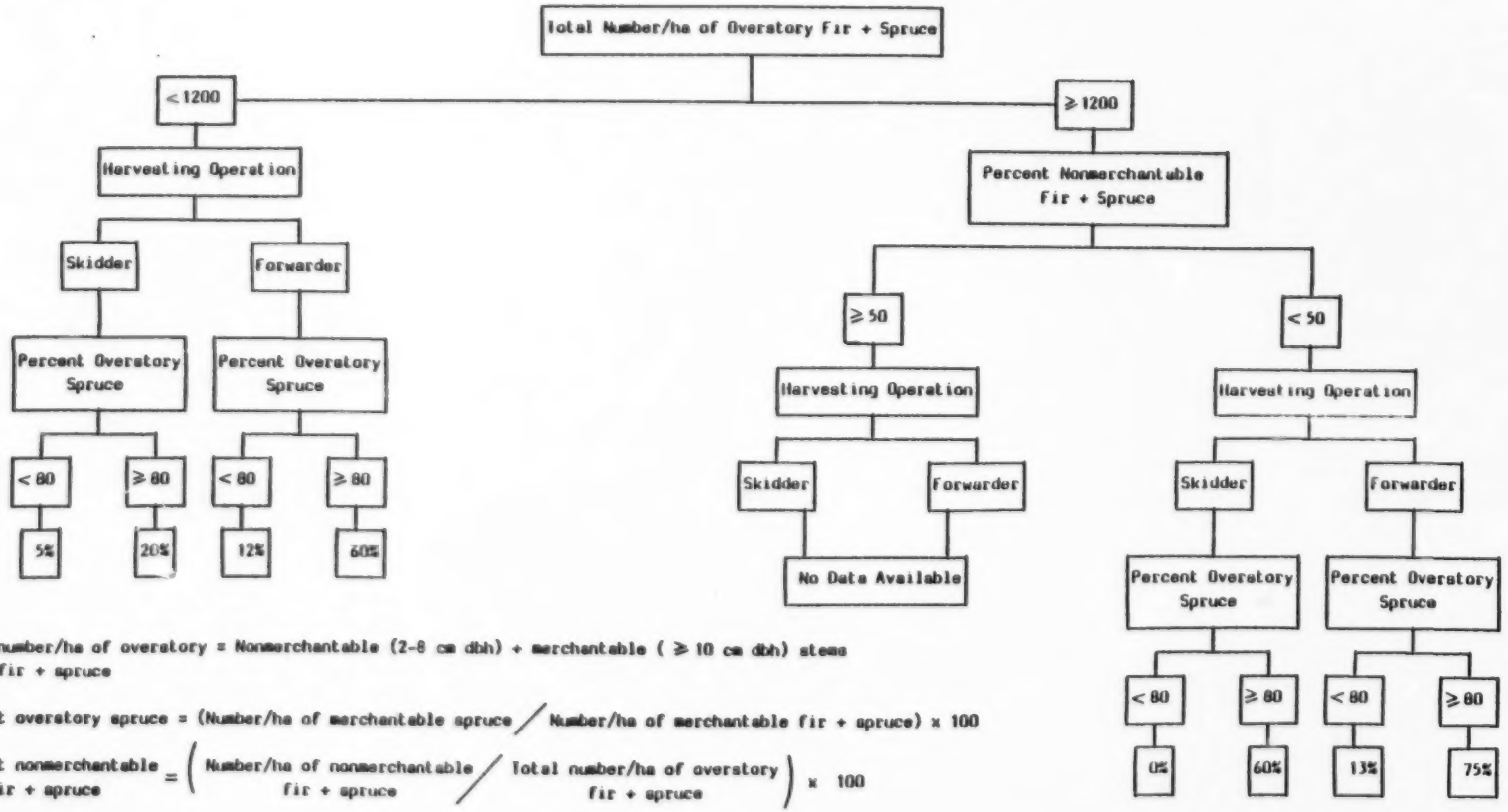


Total number/ha of overstory = Nonmerchantable (2-8 cm dbh) + merchantable (≥ 10 cm dbh) stems
fir + spruce

Percent overstory spruce = (Number/ha of merchantable spruce / Number/ha of merchantable fir + spruce) x 100

$$\text{Percent nonmerchantable fir + spruce} = \left(\frac{\text{Number/ha of nonmerchantable fir + spruce}}{\text{Total number/ha of overstory fir + spruce}} \right) \times 100$$

KEY FOR DETERMINING PROBABILITY OF HAVING ≥ 60% POSTCUT STOCKING OF SPRUCE (ADVANCE GROWTH + VOLUNTEER REGENERATION) AFTER SUMMER HARVESTING

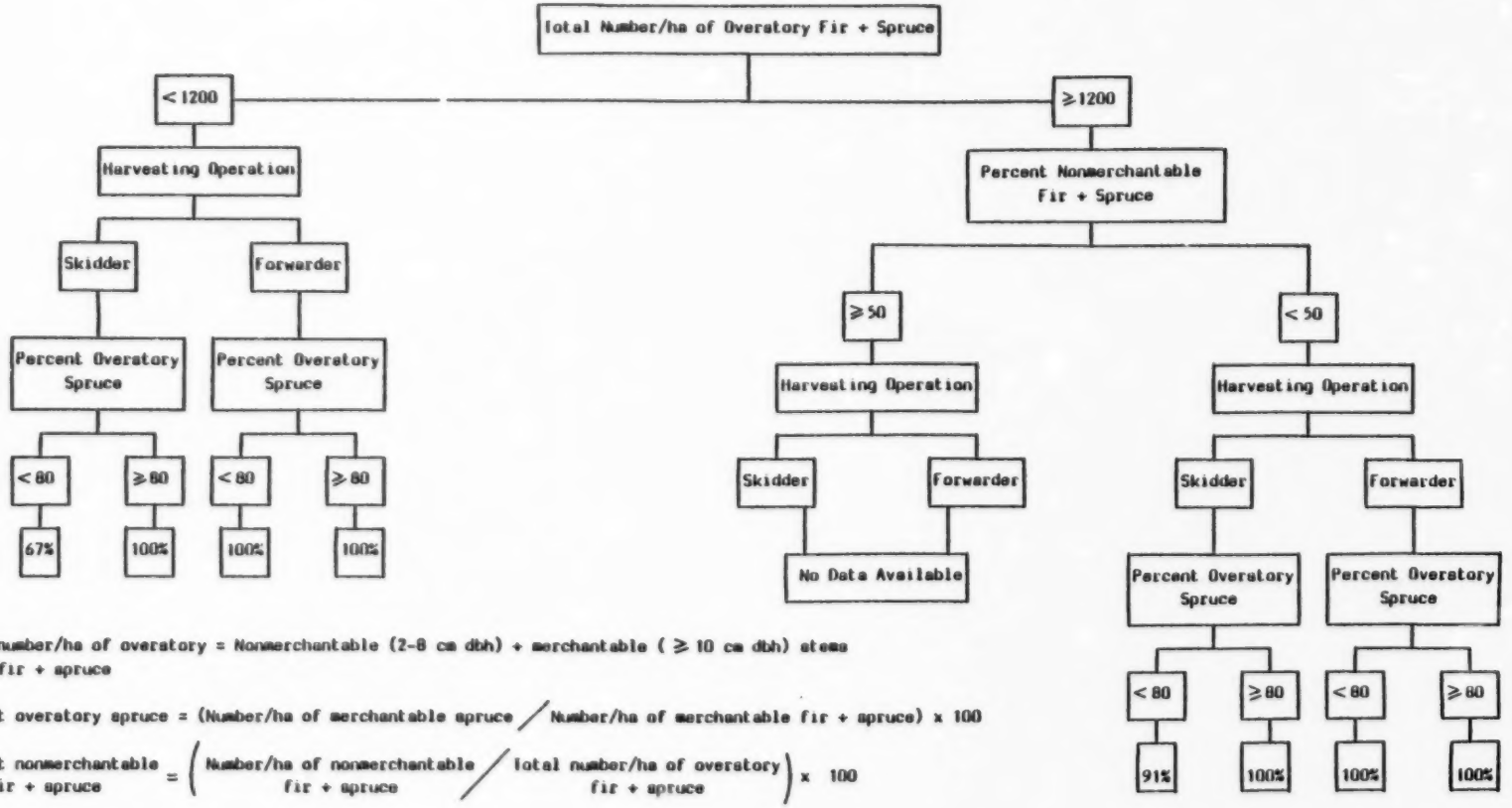


Total number/ha of overstory = Nonmerchantable (2-8 cm dbh) + merchantable (≥ 10 cm dbh) stems
fir + spruce

Percent overstory spruce = (Number/ha of merchantable spruce / Number/ha of merchantable fir + spruce) x 100

$$\text{Percent nonmerchantable fir + spruce} = \left(\frac{\text{Number/ha of nonmerchantable fir + spruce}}{\text{Total number/ha of overstory fir + spruce}} \right) \times 100$$

KEY FOR DETERMINING PROBABILITY OF HAVING ≥ 40% POSTCUT STOCKING OF FIR + SPRUCE (ADVANCE GROWTH + VOLUNTEER REGENERATION) AFTER SUMMER HARVESTING

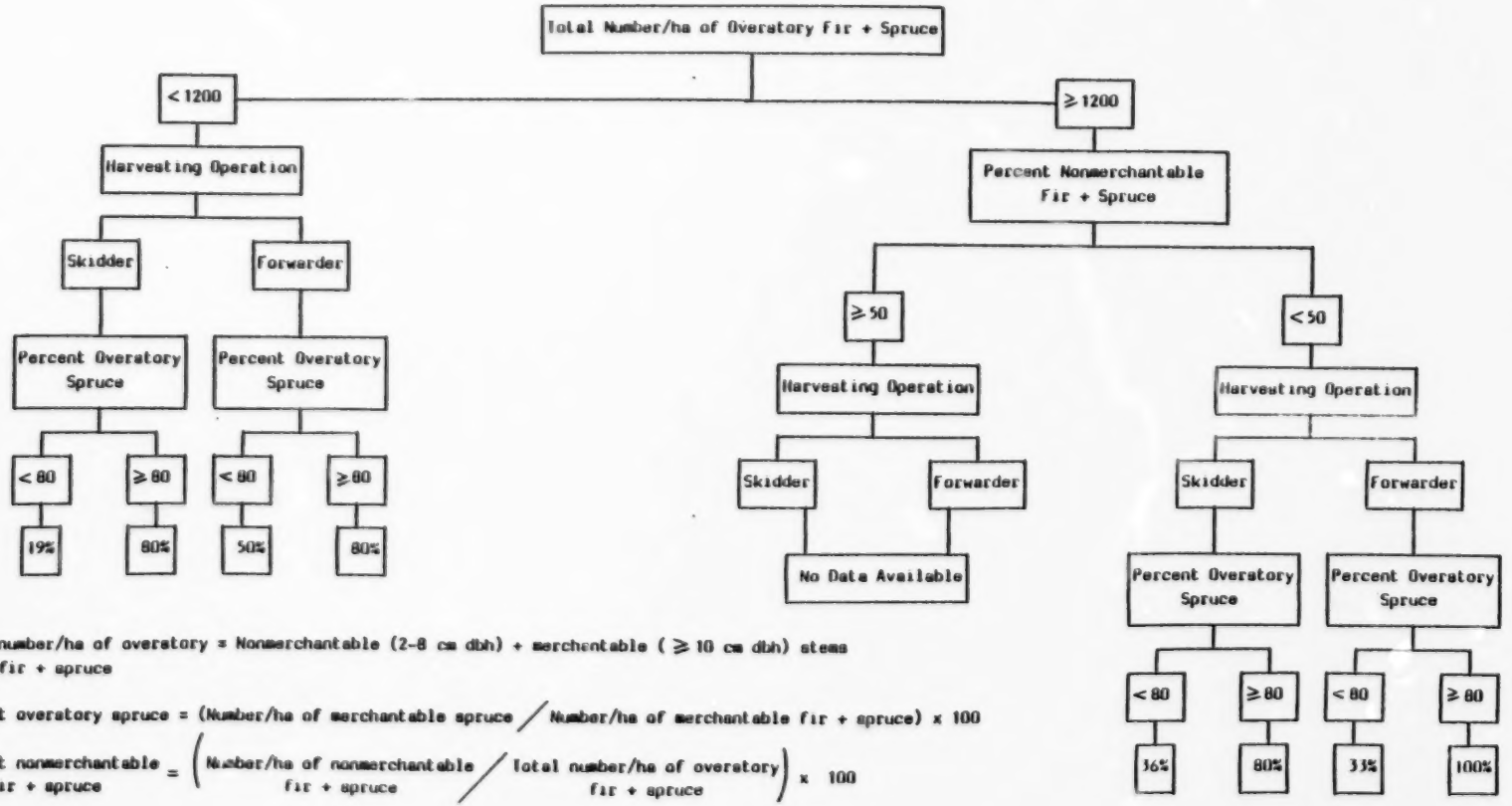


Total number/ha of overstory = Nonmerchantable (2-8 cm dbh) + merchantable (≥ 10 cm dbh) stems fir + spruce

Percent overstory spruce = (Number/ha of merchantable spruce / Number/ha of merchantable fir + spruce) x 100

$$\text{Percent nonmerchantable fir + spruce} = \left(\frac{\text{Number/ha of nonmerchantable fir + spruce}}{\text{Total number/ha of overstory fir + spruce}} \right) \times 100$$

KEY FOR DETERMINING PROBABILITY OF HAVING ≥ 40% POSTCUT STOCKING OF SPRUCE
(ADVANCE GROWTH + VOLUNTEER REGENERATION) AFTER SUMMER HARVESTING



Total number/ha of overatory = Nonmerchantable (2-8 cm dbh) + merchantable (≥ 10 cm dbh) stems
fir + spruce

Percent overatory spruce = (Number/ha of merchantable spruce / Number/ha of merchantable fir + spruce) x 100

$$\text{Percent nonmerchantable fir + spruce} = \left(\frac{\text{Number/ha of nonmerchantable fir + spruce}}{\text{Total number/ha of overatory fir + spruce}} \right) \times 100$$

APPENDIX II

LIST OF TREE AND SHRUB SPECIES

Tree Species Tallied in Study Areas

Common Name	Scientific Name
Balsam fir	*Abies balsamea* (L.) Mill.
White spruce	*Picea glauca* (Moench) Voss
Black spruce	*Picea mariana* (Mill.) B.S.P.
Red spruce	*Picea rubens* Sarg.
White pine	*Pinus strobus* L.
Eastern white cedar	*Thuja occidentalis* L.
Red maple	*Acer rubrum* L.
Sugar maple	*Acer saccharum* Marsh.
Yellow birch	*Betula alleghaniensis* Britton
White birch	*Betula papyrifera* Marsh.
Trembling aspen	*Populus tremuloides* Michx.
American mountain ash	*Sorbus americana* Marsh.

Shrub Species Tallied in Study Areas

Striped maple	*Acer pensylvanicum* L.
Mountain maple	*Acer spicatum* Lam.
Speckled alder	*Alnus rugosa* (Du Roi) Spreng.
Beaked hazel	*Corylus cornuta* Marsh.
Ericaceous species	*Ericaceae* spp.
Pin cherry	*Prunus penslyvanica* L.F.
Raspberry	*Rubus* spp.
Willow	*Salix* spp.
Red elderberry	*Sambucus pubens* Michx.
Hobblebush	*Viburnum alnifolium* Marsh.